AUGUST 21, 1989

CHEMICAL & ENGINEERING

NEWS

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CHEMICAL & ENGINEERING NEWS

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AUGUST 21, 1989

News of the Week

■ **Evidence based on DNA profiling has been thrown out in a New York City murder trial, although the same judge also ruled that the technique can be used if performed and interpreted properly.** **Page 6**

■ **Voyager 2 will reach Neptune this week to give first closeup glimpse of the outermost planet of the solar system.** **Page 7**

■ **U.S., Soviets finish productive talks aimed at limiting size of underground nuclear arms tests; joint seismic research program is being expanded.** **Page 7**

■ **New gasoline blend to be offered by Arco will replace leaded fuel, cut air pollution from older cars not equipped with catalytic converters.** **Page 8**

Cover: Photo courtesy of Air Products & Chemicals

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Business

OxyChem plans new facility, enters agreement with Canadian firm as part of effort to expand in sodium chlorate market; New Jersey-based specialty chemicals maker, Epolin, to bring expanding monomers to market. **Page 10**

Government

Most federal agencies get R&D funding boost in House appropriation actions for fiscal 1990, but Defense gets cut. **Page 15**

Science/Technology

Fast atom bombardment technique combined with HPLC offers improved analysis of bile acids; temperature, other standards of measure to change as result of international agreement; computer firms lend hardware for use at ACS molecular modeling course. **Page 20**

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In "Managing Technology: The Strategic View," Lowell W. Steele attempts to provide mind-set for the role of technology in a business framework. **Page 62**

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ACS Board approves 155 new or continuing Petroleum Research Fund grants totaling $4,106,471. **Page 66**

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PACIFICHEM '89 in Honolulu, Dec. 17-22: list of symposia, advance registration form. **Page 77**

Facts & Figures for R&D

C&EN's annual compilation of statistics for chemical research and development shows steady, if modest, growth, with 1989 expenditures expected to top $145 billion. **Page 28**

Chemical & Engineering News
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LETTERS

CHEMICAL SAFETY

Iodonium salt explosions

SIR: The current renaissance in polycoordinate iodine chemistry and in particular iodonium salt species, along with the recent report by G. v. Look (C&EN, July 24, page 2) on the explosion of iodosobenzene tetrafluoroborate, prompts us to report our own experiences with these compounds. We have also had an explosion (fortunately with no injury and only very minor damage) in the attempted preparation of an iodonium perchlorate, specifically $PhC{\equiv}C{-}I^{+}{-}Ph{\cdot}ClO_4^{-}$. In contrast, we have prepared numerous, diverse iodonium triflates and tosylates (up to 25 g scale), including $PhC{\equiv}C{-}I^{+}{-}Ph{\cdot}{}^{-}OTf({}^{-}OTs)$, and to date experienced no difficulties in the formation, handling, and subsequent transformations of these salts.

It is generally recognized that perchlorates tend to be explosive, whereas fluoroborates are much less explosive, and triflates are considered even more stable. Hence, we suggest the substitution of triflate ($CF_3SO_3^{-}$) for ClO_4^{-} in all cases where a nonnucleophilic counter ion is desired and perhaps even in some cases as substitution for BF_4^{-}. Even with triflates, ordinary caution should be exercised in the handling of all potentially explosive compounds—including the above and related polycoordinated iodine species.

Peter J. Stang
Professor of Chemistry
University of Utah

Environmental stewardship

SIR: I wonder how many caught the irony implicit in the Du Pont article on environmental stewardship (C&EN, May 29, page 12).

To start off, Edgar S. Woolard Jr. does a nice job of trying to torpedo Greenpeace and other proenvironment groups. But that's been the history of industry, both chemical and coal-stack, for too many years.

The real irony comes with Woolard's attempt to show how Du Pont is such a good guy regarding chlorofluorocarbons and ozone depletion. I well remember the almost strident tone that Du Pont took in trying very hard to refute any possibility that Mario Molina and F. Sherwood Rowland had correctly assessed the relation of CFCs and ozone. As he neatly points out, with an attempt at sugar coating, Du Pont was much more concerned with the dollars involved than with any possible environmental damage.

But this has been true in case after case in industry. The tobacco industry still claims that there is no proof connecting smoking with health damage, and they don't care how many people they kill as long as the profits keep rolling in (and do they ever).

The automobile industry fought tooth and nail against pollution control and safety restraints, and is still fighting to lower mileage requirements, which directly correlates to air pollution. Bigger engines gulp more gas (wasting more petroleum) and spew out more emissions, but the dollar profits on big engines in big cars far outweigh environmental considerations.

U.S. Steel fought aggressively to combat waste dumping controls, and thus effectively killed local marine environments around their plants. And they also fought against controlling smokestack emissions.

In summation, if you're going to have articles on environmental stewardship, maybe you should try to pick industry examples that are more meaningful than Du Pont.

Rubin Weiner
Hoffman Estates, Ill.

Cold fusion credibility

SIR: The controversy over cold fusion, which has been the subject of heated debates, newspaper editorials, and press conferences, has generated a lot of heat but very little fusion of ideas. Unfortunately, this whole episode has acquired a comic atmosphere. The strong sentiments expressed in C&EN (May 22, page 8) are an indication of the future exchanges between scientists on the two sides of this controversy.

A lingering controversy over theoretical concepts is understandable, but doubts about experimental results are unacceptable. The present situation has a historic parallel. The findings of Louis Pasteur in 1848 when he resolved sodium ammonium racemate, discovered L-tartaric acid, and laid the foundation of stereochemistry were considered extraordinary. The French Academy of Sciences requested an eminent scientist, Biot, to authenticate these results before the scientific community could accept them. Pasteur was invited to Biot's laboratory to demonstrate the accuracy of his results and all doubts were laid to rest.

Pasteur did not have to contend with patents, nor did universities use the lure of millions of dollars to guide scientific

House Completes Work on Funding Bills with Few Changes, Debates

Defense RDT&E cut but NSF and Public Health Service research funds increased in appropriation bills for federal agencies

Janice R. Long, C&EN Washington

The House completed work on all 13 of the appropriation bills needed to fund government activities in fiscal 1990, which begins Oct. 1, before Congress adjourned for its annual August recess. That was surprising in itself. Even more surprising was how few amendments were offered and how little debate was generated by these bills, which limit the amount of money that various federal departments and agencies can spend in any given fiscal year. Of the amendments offered, a number dealt with research and development matters.

For example, just three amendments were offered to the Department of Defense appropriation bill, H.R. 3072, one of which successfully deleted $10 million earmarked for the transverse-mounted engine system for armored vehicles from the Army's research, development, test, and evaluation (RDT&E) account. The House provided a total of $35.3 billion for DOD RDT&E programs in fiscal 1990. That's 5% below current spending levels and 10% less than the Administration had requested.

The Army's RDT&E budget is set at $5.6 billion, 9% above fiscal 1989 levels; the Navy's at $9.8 billion, up 4%; the Air Force's at $12.4 billion, down 14%; and that for the defense agencies at $7.5 billion, down 11%.

While cutting DOD's RDT&E budget, the House Appropriations Com-

NASA a big winner in House-approved 1990 R&D budgets

$ Millions	1990 Appropriation	1990 Request	1989	% difference Appropriation-request	% change 1989–90
Defense	$35,309.9	$39,495.4	$37,321.5	−10%	−5%
Tactical programs	12,635.2	14,595.9	13,168.7	−13	−4
Advanced technology development	5,149.9	6,623.2	5,896.8	−22	−13
Strategic programs	5,046.7	5,752.8	6,480.7	−12	−22
Intelligence and communication	4,950.5	4,763.7	4,499.1	4	10
Mission support	3,892.6	4,469.5	3,798.4	−13	2
Technology base	3,635.0	3,290.3	3,477.8	10	5
NIH	7,678.6	7,529.4	7,144.8	2	7
NASA	5,587.4	6,093.4	4,456.8	−8	25
Conduct of R&D	5,203.1	5,751.6	4,166.7	−10	25
R&D facilities	384.3	341.8	290.1	12	32
Energy	4,846.1	4,599.4	4,543.2	5	7
Energy supply R&D	**1,848.6**	**1,848.1**	**1,843.0**	**0**	**0**
Supporting research and technical analysis	690.7	671.4	642.2	3	8
Nuclear	577.5	590.3	610.5	−2	−5
Magnetic fusion	308.0	349.3	351.5	−12	−12
Other	147.8	112.5	147.8	31	0
Weapons R&D	**1,356.8**	**1,356.8**	**1,279.7**	**0**	**6**
General science and research	**1,062.4**	**1,169.4**	**922.1**	**−9**	**15**
Fossil R&D	**422.7**	**163.6**	**380.6**	**158**	**11**
Conservation R&D	**155.6**	**61.5**	**117.8**	**153**	**32**
NSF	1,999.0	2,149.2	1,922.5	−7	4
Research and related activities	1,715.0	1,803.2	1,620.5	−5	6
Science education activities	210.0	190.0	171.0	11	23
Antarctic programs	74.0	156.0	131.0	−53	−44
Commerce	1,067.8	1,016.8	1,359.7	5	−22
NOAA	966.9	849.3	1,091.7	14	−11
NIST[a]	na	155.6	159.0		
PTO	101.9	101.9	109.0	0	−7
USDA	1,088.9	1,028.8	1,045.1	6	4
Agricultural Research Service	591.5	581.1	563.4	2	5
Cooperative State Research Service	319.6	295.4	315.4	8	1
Forest Service research	149.4	133.8	137.9	12	8
Buildings and facilities	28.4	18.5	28.4	53	0
EPA R&D	431.0	421.5	386.5	2	12
TOTAL	$58,008.7	$62,333.9	$58,180.1	−7%	0%

Note: All numbers are estimates. a No funds provided for NIST because it lacks a 1990 authorization. **na** = not available.

mittee found room for lump-sum increases totaling $158 million for DOD's technology base programs that provide funds for basic research and which, as the committee noted, did not benefit from the rapid weapons system RDT&E increases that occurred between 1981 and 1985.

However, the committee went along with the Administration's decision to cut funding for university research sciences by over 30% to $96 million and cut an additional $27 million from the three armed services' budget requests for laboratory equipment. In its report on H.R. 3072, the committee cited a report by DOD's inspector general that found that up to 17,000 items of laboratory equipment valued at over $140 million are lost, stolen, missing, or not recorded in property records as one reason for reducing the laboratory equipment account.

The House appropriated a total of $12.6 billion for the Public Health Service in fiscal 1990. That amount is 7% above current funding and 2% more than requested. It includes about $1.6 billion for research, education, and other activities directed at prevention and treatment of acquired immune deficiency syndrome (AIDS). As the committee noted in its report on H.R. 2990, this represents an increase of about 25% of current spending on AIDS. However, it said, "the exact amount for AIDS-related biomedical research will be determined through the peer review system as applied by the various institutes at the National Institutes of Health and the Alcohol, Drug Abuse & Mental Health Administration."

Total funding for the National Institutes of Health was set at $7.7 billion, an increase of 7% over current funding and 2% over the Administration's budget request. The overwhelming majority of the individual institutes are slated for budget increases of 4 to 6%, barely enough to keep up with inflation. It's estimated that NIH will be able to fund only about 30% of the research proposals it will receive in fiscal 1990. The one exception is the National Institute of Allergy & Infectious Diseases, whose budget is up 14% to $845 million, just slightly over the amount requested.

The committee added $60 million to the budget request for NIH buildings and facilities; $44.4 million for biomedical research support grants; $34 million for a new supercomputer; and $32 million for high-priority extramural and intramural research projects. It deleted $38 million from the $100 million requested for the National Center for Human Genome Re: .arch, which still leaves the center with a 25% funding increase to $62 million.

The National Aeronautics & Space Administration was the biggest winner in R&D budget increases. The House gave it a 25% increase over current funding to $5.6 billion, and that's still 8% below what

Everything.

*Trademark of The Dow Chemical Company

the Administration wanted. The House provided $1.7 billion for the space station, $395 million less than requested. The Appropriations Committee admitted that the decrease may cause a slip in the scheduled March 1995 launch of the first element of the space station but said it had no alternative given the amount of money it had to work with in the Veterans Affairs, Housing & Urban Development, and Independent Agencies allocations.

The full House accepted two amendments to NASA's R&D budget offered by Rep. Robert A. Roe (D.-N.J.), chairman of the Science, Space & Technology Committee. One amendment earmarks $98 million for the national aerospace plane; the committee had allotted $78 million for it. Another Roe amendment struck language that would have allowed NASA to enter into a contract with California Institute of Technology for construction of the observational instruments laboratory at Jet Propulsion Laboratory for a total cost of not more than $14 million. Roe objected to the facility's not having been authorized by his committee.

For the Department of Energy's R&D programs, the House increased funding 7% above current levels to $4.8 billion. For research and related activities at the National Science Foundation, it increased funding 6% to $1.7 billion. And for the Department of Agriculture's research programs, it raised funding 4% to $1.1 billion (C&EN, July 31, page 5).

It's impossible to determine overall funding for the Department of Commerce's R&D programs at this time, because a fiscal 1990 authorization bill for the National Institute of Standards & Technology has yet to be enacted; thus no money can be appropriated by the House for NIST. The necessary legislation is expected to be ready for floor action soon after Congress returns on Sept. 6.

However, funding for the National Oceanic & Atmospheric Administration's operations, research, and facilities account, going counter to the trend for other nondefense R&D programs, is down 11% to $967 million. The Administration had been seeking a 22% cut. Funding for the Patent & Trademark Office is down 7% to $102 million, the requested level. However, the reduction in appropriated funds should be more than offset by increased patent and trademark fee collections.

Funding for the Environmental Protection Agency's R&D programs is up about 12% to $431 million. Funding for extramural research is up 19% to $242 million. Of that, up to $11.6 million can be used to purchase laboratory equipment.

By law, the Senate must wait for the House to act first on all appropriation bills. But if the Senate follows the House's example of speedy action on its appropriation bills, the federal government might start fiscal 1990 with a budget in place. □

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Facts & Figures for Chemical R&D

Rebecca L. Rawls, C&EN Washington

"Steady as she goes" is an apt description of research and development in the U.S. as the 1980s draw to a close. The big increases in R&D spending from the federal government of five and six years ago, particularly for defense, have leveled off, leaving an R&D effort that is substantially larger than it was at the beginning of the decade, but also one that is growing more slowly.

Total spending on R&D will top $145 billion in 1989, C&EN estimates, a 6% rise over similar estimates for 1988. That would make 1989 the fourth year running to post a 6% gain in overall R&D outlays in the U.S. This year's growth is down from the 14 and 15% gains made in some years early in the decade. Still, it represents steady, if unspectacular, growth.

The difference between the early 1980s and the past few years is less when inflation is taken into account. At its present relatively low 3 to 4% per year level, inflation accounts for about half the growth in overall R&D dollars experienced from 1986 through 1989. Early in the decade, inflation was as high as 10% per year and claimed a bigger share of R&D's year-to-year growth. It whittled 1981's 15% rise in R&D spending down to only a 5% gain in inflation-adjusted dollars, for example. That 5% increase is the rate at which overall R&D was growing each year a decade ago, after adjusting for inflation. For a brief time from 1983 to 1985, big increases in defense-related R&D pushed real growth in R&D in the U.S. as high as 10% per year. Thus, the present 3%-per-year, inflation-adjusted increase (since 1986) is noticeably less than the growth that was taking place earlier in the decade.

Another shift has occurred during the past decade. The fraction of the total R&D effort that is defense-related has increased. Ten years ago defense-related R&D made up 23% of the total. Its share climbed rapidly in the early Reagan years to reach 34% by 1987. It now has dropped back to about 31%. Dollar-for-dollar, defense R&D benefits the civilian economy less than other types of R&D, so not only are present R&D budgets growing more slowly than a decade ago, but their long-term beneficial effects on the economy as a whole are likely to be smaller as well.

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Research Triangle Institute photo

OHM Corp. photo

Steadiness is also apparent in the share of the gross national product (GNP) claimed by R&D in recent years. After growing dramatically from a low of 2.1% in 1978 to just over 2.8% in 1985, this percentage has hovered at about 2.8% or 2.9% for the past five years. Nondefense R&D leveled off sooner; it's held steady since 1982 at 1.9% of the value of all goods and services produced in the U.S.

This measure is particularly useful in comparing the R&D efforts of different countries, since it factors in the relative size of the economies of various nations. In absolute terms, of course, the U.S. R&D effort dwarfs that of any other noncommunist country. (Comparisons with communist countries, with their very different economic structure, are not very meaningful.) In fact, in 1987—the most recent year for which most comparative data are available—U.S. R&D spending was more than the combined R&D expenditures of any 10 other countries for which data are available from the National Science Foundation. It was 2.8 times that of Japan, the next largest R&D spender.

But such comparisons are less useful than looking at R&D as a fraction of GNP for various countries. By this standard, the U.S. 1987 level of 2.9% matches that of Japan and marginally trails both Sweden and Israel, which each spent 3.0% of their GNP on R&D in the most recent year for which such data are available for each country. West Germany, at 2.8% of GNP, is also among the big spenders by this measure. The U.K., France, Switzerland, and the Netherlands spend between 2.0 and 2.5% of their GNP on R&D, and many other high-technology-based economies—such as Canada, Italy, Belgium, South Korea, and Taiwan—spend between 1.0 and 1.9%. Third World countries, not surprisingly, generally spend considerably less.

A look at the U.S.'s chief competitors in high-technology areas, those that benefit the most from R&D, shows that Japan and West Germany, like the U.S., steadily increased their R&D as a portion of their GNP throughout the early 1980s. Unlike the U.S., this percentage was still climbing for both of these countries in 1987, the last year for which figures are available. In 1987, all three countries spent either 2.8% or 2.9% of their GNP on R&D. There is a considerable difference in the nondefense R&D spending of the three countries, however; both Japan and West Germany spend a much smaller fraction of their R&D on defense. Although U.S. nondefense R&D plateaued at 1.9% of GNP in 1982, that of Japan and West Ger-

many continued to climb through 1985, reaching levels of 2.6% for West Germany and 2.8% for Japan in that year.

Another measure of the effect of R&D on the technology-intensive part of the economy, and one that focuses more directly on chemical technology, is of U.S. patent activity in recent years. Although most U.S. chemical patents are still issued to U.S. corporations, individuals, or the federal government, they accounted for only 52% of the total last year. A decade earlier, U.S. recipients claimed 60% of these patents. Over the past decade, West Germany has received a steady 10 to 11% of the total, but Japan has increased its share every year—from 11% in 1979 to 20% in 1988. The U.K., France, Switzerland, and Canada round out the nations that claimed more than 1% of U.S. chemical patents last year. In fact, of the 20 corporations receiving the greatest number of chemical patents last year, only 15 are based in the U.S. and the other five have headquarters in West Germany, Japan, and the U.K.

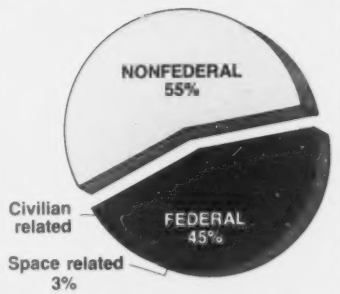
The 6% increase for total R&D spending in the U.S. this year and last provides a healthy climate for R&D in chemistry and chemical engineering. No recent data are available for measuring the total number of dollars going into chemical R&D of all types. However, a few clues provide some insight.

NSF estimates that the federal government was the source for $677 million in funds for chemical research in the past fiscal year (a figure that excludes money spent for development work), essentially unchanged from the amount government agencies provided in the year before. Three quarters of these funds came from just four agencies: the departments of Energy, of Defense, and of Health & Human Services, and from NSF. Federal agencies also are estimated by NSF to have provided $245 million for chemical engineering research, a 13% boost from fiscal 1987 to a level about the same as in 1986 and 1985. All told, though, government support of chemical and chemical engineering research is relatively modest, accounting for a mere 5% of federal outlays for all scientific research. The life sciences, physics, and environmental sciences are recipients of far heftier sums of money.

Even fewer chemical R&D dollars are funded by the universities. In 1987 (the most recent year for which figures are available), chemical R&D spending at universities totaled $508 million; for chemical engineering the total was $140 million. But 72% of the chemical funds and half of those for chemical engineering were provided by the federal government, leaving just about $200 million that was provided by the universities themselves, by industry, or by other sources. The amount of nonfederally funded chemical and chemical engineering R&D has nearly tripled since 1980. Even so, it still amounts to relatively few dollars.

The results of chemical research have proven commercial value. Consequently, it is not surprising that industry is by far the most generous supporter of chemical and chemical engineering R&D, especially the chemical industry itself. Last year, C&EN estimates, the amount of money plowed by all U.S. industry into R&D increased 6%—to top $100

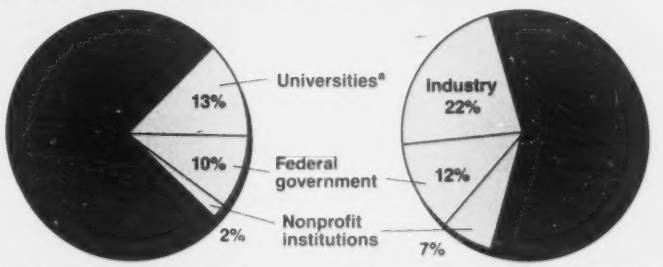
Federal funds account for almost half of all U.S. R&D



Estimated 1989 total R&D spending = $145 billion

Source: C&EN estimates based on data from the National Science Foundation

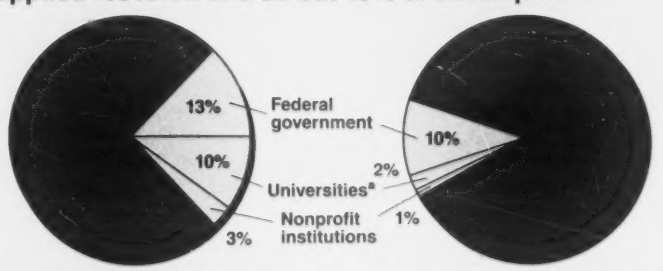
Industry performs three quarters of all R&D, even though universities do most basic research...



Estimated 1989 total R&D spending = $145 billion

Estimated 1989 basic research spending = $20 billion

...because it accounts for nearly three quarters of applied research and all but 13% of development



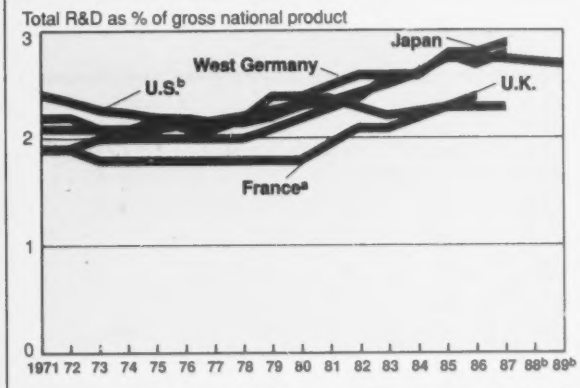
Estimated 1989 applied research spending = $34 billion

Estimated 1989 development spending = $91 billion

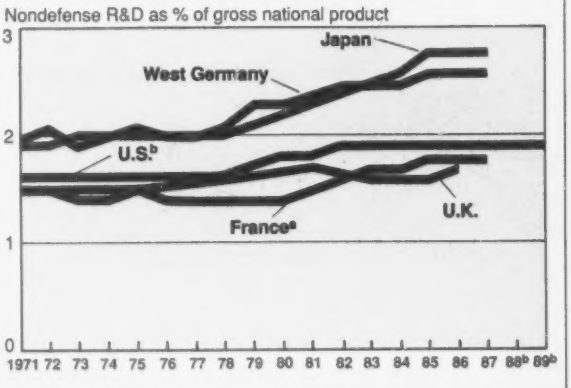
a Includes associated federally funded R&D centers.

Source: C&EN estimates based on data from the National Science Foundation

U.S., Japan, and West Germany set pace on overall R&D effort . . .



. . . but when only nondefense R&D is considered, U.S. does less well



a French data are based on gross domestic product, consequently percentages may be slightly overstated. b C&EN estimates. **Source:** National Science Foundation

billion for the first time ever. Outlays by producers of chemicals and allied products, meanwhile, rose 11% to $11 billion, thanks largely to a 17% boost by drugmakers, who are easily the biggest R&D spenders in the overall chemical industry.

Data from earlier years indicate that about 70% of the R&D done by the chemicals and allied products industry, as well as 3% of that performed by all other industries, is focused on various aspects of chemical science or technology. This suggests, therefore, that last year industry devoted something on the order of $10.4 billion to work in chemical fields. Relatively little of this money comes from federal agencies, probably less than $400 million.

Couple that $10 billion in expenditures by industry with the roughly $1 billion divvied up from nonindustrial sources, and the total U.S. funding for chemical and chemical engineering R&D came to roughly $11 billion in 1988—about 8% of the money that went into all types of R&D.

There are a few changes this year in the tables that make up the main body of Facts & Figures of R&D. Added is a new international section, comparing the U.S. R&D effort with that of some 20 other nations, but particularly with that of Japan, West Germany, the U.K., and France. Presentation of estimated figures in the tables in many sections has been changed. Data for this report come from several sources, but the great bulk of the information is compiled by NSF's division of science resources studies. NSF collects the most comprehensive information on U.S. R&D and is the only source of many of the detailed breakdowns showing where that effort is focused. But compiling data with such completeness and detail is time-consuming, and NSF usually needs about a year and a half to publish its information. To make its data more current, NSF in many cases estimates recent levels of spending, estimates that are constantly being revised. And C&EN sometimes additionally revises these estimates, based on more current information from NSF as well as from other sources.

Every figure in this report for 1989, of course, is an estimate, and many of those for 1988 are as well. Although C&EN always indicates which data in the tables are estimates, this year the columns of tables that contain estimated data also are shaded. In addition, data for annual changes included in many tables are now calculated for the most recent year for which firm historical data are available—generally 1987—rather than for years for which only estimates are available. (Experience has suggested that estimates for R&D spending can turn out to be well off the mark.) □

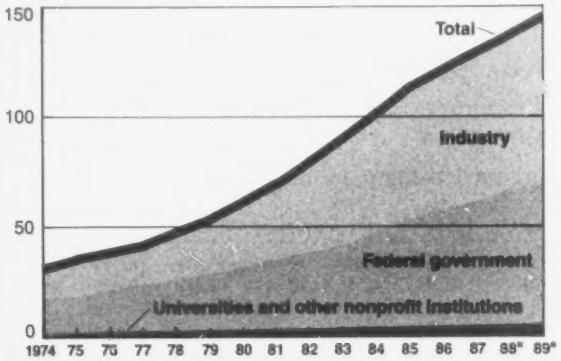
For further information

Information for this Special Report is collected from many sources, but one important one is the National Science Foundation's division of science resources studies. This division publishes detailed statistical studies of each of the areas covered in this report. The studies contain a great deal of information not included here. Further overview information on the U.S. R&D effort is available in "National Patterns of R&D Resources: 1989," NSF publication No. 89-308. More information on funding from the federal government is in "Federal Funds for Research and Development, Fiscal Years 1987, 1988, and 1989," NSF publication No. 89-304. Industry data are provided in "Research & Development in Industry, 1987." Detailed information on universities and colleges is in "Academic Science/Engineering: R&D Funds, Fiscal Year 1987," and international comparisons may be found in "International Science & Technology Data Update: 1988," NSF publication No. 89-307. These studies are available in paper form or in some cases on diskettes from the National Science Foundation, Division of Science Resources Studies, Office of the Director, 1800 G St., N.W., Washington, D.C. 20402, telephone (202) 634-4622.

Steady Growth Brings R&D to $145 Billion

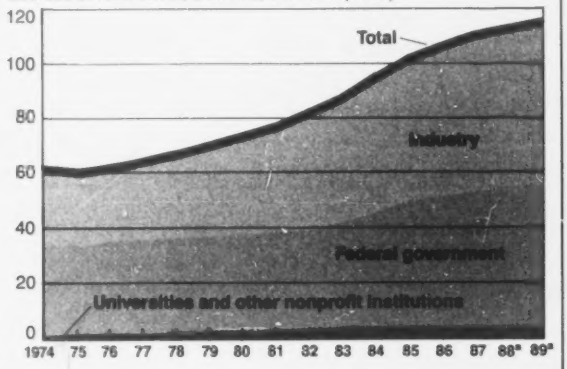
Spending on R&D in the U.S. has nearly doubled since 1981...

Sources of R&D funds, $ billions, current



...but is growing more slowly now, in real terms, than in the early 1980s

Sources of R&D funds, $ billions, constant (1982)



Note: Industry data for 1982–89 are C&EN estimates. a Estimated. **Source:** National Science Foundation

SOURCES OF R&D FUNDS: Industry provides half, universities' small share is growing

$ Billions, current	1989a	1988a	1987	1986	1985	1984	1983	1982	1981	1980	1979	1978	1977	Annual change 1986–87	Annual change 1977–87
Industry	$ 74.9	$ 70.7	$ 66.3a	$ 63.1a	$ 59.6a	$ 53.6a	$45.8a	$41.1a	$35.9	$30.9	$26.1	$22.5	$19.6	5%	13%
Federal government	64.8	61.9	58.5a	54.5a	51.8a	45.5a	40.7	36.5	33.4	29.5	26.8	23.9	21.6	5	10
Universities and colleges	3.8	3.5	3.1	2.8	2.4	2.1	1.9	1.7	1.6	1.3	1.2	1.0	0.9	13	13
Other nonprofit institutions	1.8	1.7	1.6	1.4	1.4	1.2	1.1	1.0	1.0	0.9	0.8	0.8	0.7	14	9
TOTAL	$145.3	$137.8	$129.6	$121.8	$115.1	$102.4	$89.6	$80.4	$71.9	$62.6	$54.9	$48.1	$42.8	6%	12%
ANNUAL CHANGE	6%	6%	6%	6%	12%	14%	11%	12%	15%	14%	14%	12%	10%		

$ Billions, constant 1982															
Industry	$ 59.3	$ 58.1	$ 56.3	$ 55.4	$ 53.7	$ 49.8	$44.1	$41.1	$38.2	$36.1	$33.2	$31.1	$29.2	2%	7%
Federal government	51.3	50.5	49.7	47.8	46.7	42.2	39.2	36.5	35.5	34.4	34.1	33.1	32.2	4	4
Universities and colleges	3.0	2.9	2.7	2.4	2.1	2.0	1.9	1.7	1.7	1.5	1.5	1.4	1.3	9	7
Other nonprofit institutions	1.4	1.4	1.4	1.3	1.2	1.1	1.1	1.0	1.0	1.1	1.1	1.1	1.0	10	3
TOTAL	$115.0	$112.9	$110.1	$106.9	$103.8	$95.1	$86.2	$80.4	$76.5	$73.0	$69.9	$66.7	$63.7	3%	6%
ANNUAL CHANGE	2%	3%	3%	3%	9%	10%	7%	5%	5%	5%	5%	5%	2%		

Note: Constant-dollar values are calculated by C&EN based on NSF data. a C&EN estimates. **Source:** National Science Foundation

PERFORMERS OF R&D: Industrial R&D, three fourths of total, now tops $100 billion

$ Billions, current	1989[a]	1988[a]	1987	1986	1985	1984	1983	1982	1981	1980	1979	1978	1977	Annual change 1986–87	Annual change 1977–87
Industry	$108.2	$102.3	$ 96.3[a]	$ 89.9[a]	$ 85.6[a]	$ 76.1[a]	$65.7[a]	$59.0[a]	$51.8	$44.5	$38.2	$33.3	$29.8	7%	12%
Federal government	14.8	14.5	13.4	13.5	12.9	11.6	10.6	9.1	8.4	7.6	7.4	6.8	6.0	−1	8
Universities and colleges	13.9	13.0	12.1	10.9	9.7	8.6	7.9	7.3	6.8	6.1	5.4	4.6	4.1	11	11
University-associated FFRDCs[b]	4.7	4.4	4.2	3.9	3.5	3.1	2.7	2.5	2.5	2.2	1.9	1.7	1.4	8	12
Other nonprofit institutions	3.7	3.6	3.6	3.5	3.3	3.0	2.7	2.4	2.3	2.2	2.0	1.7	1.5	2	9
TOTAL	$145.3	$137.8	$129.6	$121.8	$115.1	$102.4	$89.6	$80.4	$71.9	$62.6	$54.9	$48.1	$42.8	6%	12%
$ Billions, constant 1982															
Industry	$ 85.7	$ 84.1	$ 81.8	$ 78.9	$ 77.2	$ 70.7	$63.2	$59.0	$55.1	$51.9	$48.7	$46.1	$44.3	4%	6%
Federal government	11.7	11.9	11.4	11.9	11.7	10.7	10.2	9.1	9.0	8.9	9.4	9.4	9.0	−4	2
Universities and colleges	11.0	10.7	10.3	9.6	8.7	8.0	7.6	7.3	7.3	7.1	6.8	6.4	6.1	7	5
University-associated FFRDCs[b]	3.7	3.6	3.6	3.4	3.2	2.9	2.6	2.5	2.6	2.6	2.5	2.4	2.1	4	5
Other nonprofit institutions	2.9	3.0	3.0	3.1	3.0	2.8	2.6	2.4	2.4	2.5	2.5	2.3	2.2	−1	3
TOTAL	$115.0	$113.2	$110.1	$106.9	$103.8	$ 95.1	$86.2	$80.4	$76.5	$73.0	$69.9	$66.7	$63.7	3%	6%

Note: Constant-dollar values are calculated by C&EN based on NSF data. a C&EN estimates. b Federally funded R&D centers. **Source:** National Science Foundation

U.S. CHEMICAL PATENTS: Nearly half go to foreign corporations, individuals, or governments

Number of patents issued	1988	1987	1986	1985	1984	1983	1982	1981	1980	1979[a]	Total 1979–88
U.S. origin	11,229	11,384	10,500	11,531	11,497	10,554	10,608	12,690	11,239	9,285	110,517
to U.S. corporations	9,799	9,885	9,189	10,169	10,112	9,142	9,167	10,974	9,674	8,078	96,189
to U.S. government	265	325	290	322	376	331	311	364	360	272	3,216
to individuals in the U.S.	1,012	1,046	927	989	933	985	1,029	1,278	1,127	873	10,199
to foreign-owned corporations in the U.S.	153	128	94	51	76	96	101	74	78	62	913
Foreign origin	10,529	10,248	9,110	9,697	8,996	8,068	8,016	9,618	8,361	6,440	89,083
to U.S.-owned corporations abroad	866	849	758	884	834	702	731	896	818	623	7,961
to foreign corporations	8,892	8,644	7,674	8,086	7,439	6,711	6,514	7,855	6,768	5,265	73,848
to foreign governments	194	200	148	162	167	133	166	100	96	78	1,444
to foreign individuals	577	555	530	565	556	522	605	767	679	474	5,830
TOTAL	21,758	21,632	19,610	21,228	20,493	18,622	18,624	22,308	19,600	15,725	199,600
% Foreign	48.4%	47.4%	46.5%	45.7%	43.9%	43.3%	43.0%	43.1%	42.7%	41.0%	44.6%

Note: Includes patents issued in those technology subclasses that the U.S. Patent & Trademark Office classifies as chemical. a Patent figures were low in 1979 because the U.S. Patent & Trademark Office was short of funds to print patents. **Source:** U.S. Patent & Trademark Office

Development claims nearly two thirds of all R&D funds

Estimated total 1989 R&D spending = $145 billion

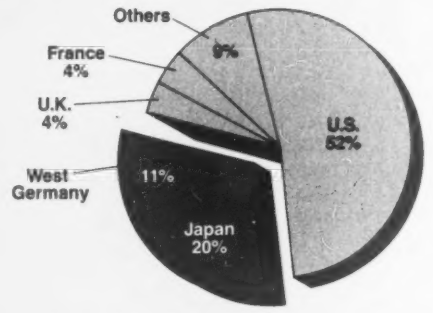
Source: C&EN estimates

RECIPIENTS OF U.S. CHEMICAL PATENTS: Japan's share has nearly doubled in past decade

% of patents	1988	1987	1986	1985	1984	1983	1982	1981	1980	1979	Total 1979–88
U.S. origin	52%	53%	54%	54%	56%	57%	57%	57%	57%	59%	55%
Foreign origin[a]	48	47	46	46	44	43	43	43	43	41	45
Japan	20	19	19	18	16	15	14	13	12	11	16
West Germany	11	10	10	10	10	11	11	11	11	11	11
U.K.	4	4	4	4	4	4	4	4	5	4	4
France	4	4	3	3	3	3	4	4	4	3	4
Switzerland	2	2	2	2	2	2	2	2	3	3	2
Canada	2	1	1	2	1	1	1	1	1	1	1
Italy	1	1	1	1	1	1	1	1	2	1	1
Netherlands	1	1	1	1	1	1	1	1	1	1	1
Sweden	1	1	1	1	1	1	1	1	1	1	1
Belgium	1	1	1	1	1	1	1	1	1	1	1
U.S.S.R.	—	—	—	—	—	—	—	1	1	1	—

Note: Includes patents issued in those technology subclasses that the U.S. Patent & Trademark Office classifies as chemical. a Data for individual countries may not equal this number because of rounding. **Source:** U.S. Patent & Trademark Office

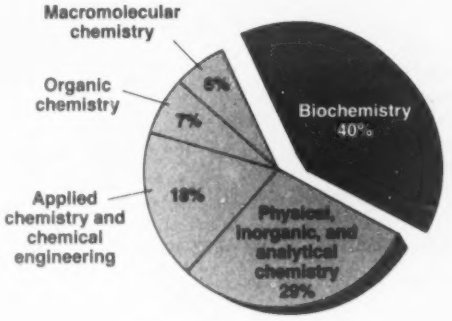
Japan and West Germany claim almost a third of U.S. chemical patents



1988 total U.S. chemical patents issued = 21,758

Source: U.S. Patent & Trademark Office

Biochemistry accounts for 40% of all papers in chemistry fields



1988 total[a] = 389,685

a Number of abstracts of papers published in *Chemical Abstracts*.
Source: Chemical Abstracts Service

PATENT ACTIVITY OF U.S. COMPANIES: Dow and Du Pont lead list for chemical firms

Number of patents issued	1988	1987	1986	1985	1984	1983	1982	1981	1980	1979[a]	Total 1979–88
CHEMICAL COMPANIES											
Dow Chemical	421	469	371	335	328	246	276	260	249	217	3,172
Du Pont[b]	375	449	371	395	416	387	331	430	349	287	3,790
Ciba-Geigy	279	286	244	305	290	244	281	345	309	248	2,831
Union Carbide	141	159	208	242	231	182	202	262	211	197	2,035
PPG Industries	118	118	124	128	137	137	177	189	166	118	1,412
American Cyanamid	101	107	92	115	111	128	129	188	205	143	1,319
Dow Corning	82	58	68	55	52	37	35	50	31	26	494
Monsanto	76	91	110	100	138	138	131	211	205	144	1,342
Stauffer Chemical	69	94	75	104	95	81	87	94	93	80	872
Olin	59	58	81	117	112	85	80	80	106	82	860
Ethyl	51	48	77	105	76	44	31	43	51	25	551
W. R. Grace	46	43	42	45	57	52	49	68	72	56	530
Hercules	32	50	43	41	39	37	30	52	23	24	371
International Flavors & Fragrances	24	38	76	104	95	87	87	96	76	60	743
GAF	23	15	12	23	19	21	32	47	48	54	294
Rohm & Haas	18	22	33	31	37	55	49	77	74	77	473
TOTAL[c]	1915	2105	2027	2245	2233	1959	2007	2492	2268	1838	21,089
ANNUAL CHANGE	−9%	4%	−10%	1%	14%	−2%	−19%	10%	23%	−49%	
DRUG COMPANIES											
Merck	125	123	103	105	135	114	135	160	156	127	1,283
Warner-Lambert	113	118	101	73	49	34	25	37	36	36	622
Squibb	74	75	70	74	53	37	56	62	85	98	684
American Home Products	69	46	38	49	32	24	43	52	52	39	444
Eli Lilly	68	85	82	107	80	74	104	112	85	84	881
Pfizer	63	67	72	72	89	61	72	92	75	65	728
Hoffmann-LaRoche	59	86	84	74	78	90	118	124	144	126	983
SmithKline Beckman	56	54	27	43	68	59	66	59	82	71	585
Upjohn	15	26	66	66	107	73	122	337	170	196	1,178
TOTAL[c]	642	680	643	663	691	566	741	1035	885	842	7,388
ANNUAL CHANGE	−6%	6%	−3%	−4%	22%	−24%	−28%	17%	5%	−33%	

Note: Includes U.S. chemical and drug companies and U.S. subsidiaries of foreign companies that have received more than 1000 U.S. patents since 1962. a Patent figures were low in 1979 because the U.S. Patent & Trademark Office was short of funds to print patents. b Includes patents issued to Conoco, acquired in 1981, for all years. c These totals include patents issued to companies in this table only. **Source:** U.S. Patent & Trademark Office

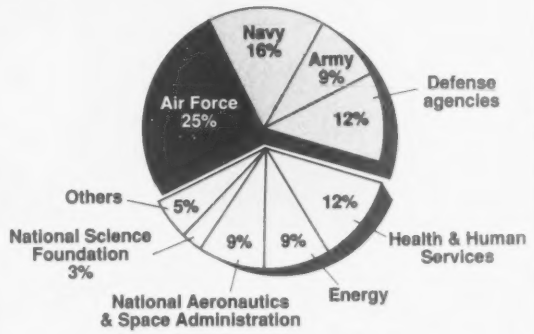
ABSTRACTS OF PAPERS IN *CHEMICAL ABSTRACTS:* Biochemistry's dominant share down slightly

	1988	1987	1986	1985	1984	1983	1982	1978	Change 1977–87
BIOCHEMISTRY	39.7%	40.5%	40.4%	40.5%	40.5%	38.3%	39.5%	38.3%	1.4%
% of all biochemistry abstracts									
Mammalian hormones[a]	12.7	12.2	12.5	12.3	12.4	12.9	12.2	12.3	0.4
Pharmacology	12.0	12.6	12.2	12.3	11.6	11.8	12.0	5.9	6.1
Mammalian biochemistry[a]	10.8	11.1	10.8	11.1	11.3	11.1	11.6	17.2	−6.4
Toxicology	7.9	8.3	7.8	7.9	8.0	8.5	8.1	7.5	0.4
Biochemical genetics[b]	7.6	6.7	6.1	5.2	4.2	3.8	3.3	—	—
Enzymes	6.1	5.4	5.6	5.6	5.8	6.1	5.9	5.7	0.4
Immunochemistry	5.8	5.8	6.1	5.3	4.8	4.2	4.4	3.6	2.2
General biochemistry	5.3	4.6	4.7	4.9	5.3	5.8	6.0	6.5	−1.2
Biochemical methods	5.1	4.8	5.0	4.9	4.9	4.9	4.6	4.6	0.5
Plant biochemistry[a]	5.0	5.3	5.2	5.5	6.2	5.9	6.2	5.4	−0.4
Microbial biochemistry[a]	4.8	5.1	5.7	5.7	5.2	5.1	5.3	5.1	−0.3
Others	16.9	18.1	18.3	19.3	20.3	19.9	20.4	26.2	−9.3
TOTAL	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	—
PHYSICAL, INORGANIC, AND ANALYTICAL CHEMISTRY	28.8%	29.0%	29.8%	29.8%	28.8%	29.6%	28.5%	27.4%	1.4%
% of all physical, inorganic, and analytical chemistry abstracts									
Spectra	20.0	20.4	20.0	18.4	18.0	17.6	17.2	17.0	3.0
Nuclear chemistry	17.8	19.5	19.9	21.8	22.2	22.5	22.6	20.7	−2.9
Electric phenomena	12.5	10.9	10.8	10.8	10.8	10.0	10.5	10.9	1.6
General physical chemistry	7.2	7.9	7.0	6.9	6.9	7.3	7.3	6.6	0.6
Crystallography and liquid crystals	7.0	7.1	7.0	7.5	7.8	8.3	8.7	9.2	−2.2
Analytical chemistry	5.7	5.9	6.8	6.1	6.3	6.2	5.4	7.2	−1.5
Others	29.8	28.3	28.5	28.5	28.0	28.1	28.3	28.4	1.4
TOTAL	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	—
APPLIED CHEMISTRY AND CHEMICAL ENGINEERING	18.6%	18.0%	18.2%	18.4%	17.6%	19.4%	19.5%	20.8%	−2.2%
% of all applied chemistry and chemical engineering abstracts									
Metals and alloys	21.7	20.6	20.8	20.0	18.9	19.1	22.2	24.0	−2.3
Water, wastes, and pollution	20.4	20.4	21.9	20.2	21.0	19.6	21.7	20.8	−0.4
Mineralogical and geological chemistry	11.8	11.2	12.0	12.5	14.6	14.1	13.6	16.8	−5.0
Fossil fuels, derivatives, and related products	8.8	9.6	9.0	10.1	10.1	10.3	9.4	8.2	0.6
Unit operations and processes	8.0	9.0	7.1	7.5	7.0	7.5	6.9	6.4	1.6
Pharmaceuticals and pharmaceutical analysis	7.6	7.8	8.2	8.0	7.0	6.5	6.3	5.6	2.0
Ceramics	6.7	6.3	5.8	5.6	5.1	5.4	4.5	4.1	2.6
Others	15.0	15.1	15.2	16.1	16.3	17.5	15.4	14.1	0.9
TOTAL	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	—
ORGANIC CHEMISTRY	7.3%	6.9%	5.9%	6.4%	7.6%	7.3%	7.2%	8.0%	−0.7%
% of all organic chemistry abstracts									
Physical organic chemistry	23.0	23.9	27.3	30.6	32.0	30.5	31.5	36.8	−13.8
Organometallic and organometalloidal compounds	18.8	16.1	18.3	16.2	17.1	16.3	14.8	17.5	1.3
Heterocyclic compounds[a]	15.7	19.9	15.0	16.1	15.6	16.2	15.6	8.9	6.8
Carbohydrates	8.1	5.6	7.8	5.7	5.7	5.8	5.8	5.2	2.9
Aromatic compounds[a]	7.2	7.7	7.3	6.3	6.3	7.1	7.2	8.6	−1.4
Biomolecules and their synthetic analogs[b]	6.1	5.8	5.0	4.9	4.4	4.5	3.7	—	—
Amino acids, peptides, and proteins[a]	5.8	4.3	3.9	4.6	4.8	4.5	4.4	4.0	1.8
Aliphatic compounds[a]	4.1	4.9	4.4	4.2	3.6	4.3	5.2	6.9	−2.8
Others	11.2	11.8	11.0	11.4	10.5	10.8	11.8	12.1	−0.9
TOTAL	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	—
MACROMOLECULAR CHEMISTRY	5.6%	5.6%	5.7%	4.9%	5.5%	5.4%	5.3%	5.5%	0.1%
% of all macromolecular chemistry abstracts									
Synthetic high polymers	34.8	35.2	34.1	34.1	34.0	34.4	34.7	25.6	9.2
Plastics manufacture and uses	23.7	23.6	23.8	25.3	24.2	24.4	21.9	28.1	−4.4
Cellulose, lignin, paper, and other wood products	9.6	8.8	9.8	9.1	9.6	9.1	9.7	10.6	−1.0
Textiles	7.3	8.1	8.8	8.2	7.3	7.9	8.9	12.1	−4.8
Synthetic elastomers and natural rubber	6.7	7.2	6.7	6.8	7.3	7.5	7.8	7.5	−0.8
Coatings, inks, and related products	5.7	5.8	7.2	7.2	7.8	6.6	7.6	8.0	−2.3
Others	12.2	11.3	9.6	9.3	9.8	10.1	9.4	8.1	4.1
TOTAL	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	—

How to read this table: Using biochemistry as an example, in 1988 39.7% of all the papers abstracted by Chemical Abstracts Service are in the various subdisciplines of biochemistry; 12.7% of all abstracts in biochemistry, in turn, are in the subdiscipline of pharmacology, and so on. a Definition of section changed in 1982. b New section in 1982. **Source:** Chemical Abstracts Service

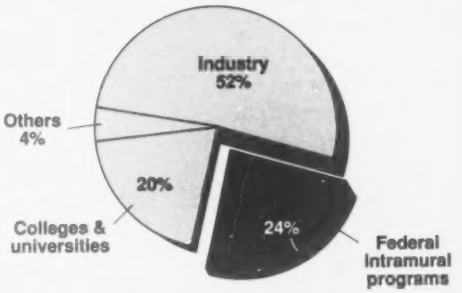
Defense's Mammoth Share Is Leveling Off

A fourth of federal R&D outlays comes from Air Force . . .



Estimated fiscal 1989 total federal R&D obligations = $60.3 billion

. . . and about a fourth of the R&D is performed at federal facilities



Estimated fiscal 1989 total federal R&D obligations = $60.3 billion

Source: National Science Foundation

FEDERAL OBLIGATIONS FOR R&D: Growth in health, space, and at NSF outpace that at DOD

$ Millions	1989[a]	1988[a]	1987	1986	1985	1984	1983	1982	Annual change 1986–87	Annual change 1982–87
Defense	**$37,505**	**$36,543**	**$35,232**	**$32,938**	**$29,792**	**$25,373**	**$22,993**	**$20,623**	**7%**	**11%**
Air Force	15,279	15,520	15,348	13,594	13,261	12,092	10,813	9,358	13	10
Navy	9,432	9,631	9,508	9,650	9,127	7,606	6,068	5,845	−1	10
Army	5,250	4,921	5,020	4,809	4,571	4,226	3,998	3,761	4	6
Defense agencies	7,246	6,244	5,220	4,767	2,782	1,392	2,052	1,618	9	26
Health & Human Services	**7,043**	**7,112**	**6,609**	**5,658**	**5,451**	**4,831**	**4,353**	**3,941**	**17**	**11**
National Institutes of Health	6,233	6,321	5,853	5,005	4,828	4,257	3,789	3,433	17	11
Alcohol, Drug Abuse & Mental Health Administration	523	498	476	396	378	337	302	248	20	14
National Aeronautics & Space Administration	**5,416**	**4,779**	**3,787**	**3,420**	**3,327**	**2,822**	**2,662**	**3,078**	**11**	**4**
Energy	**5,182**	**5,101**	**4,757**	**4,688**	**4,996**	**4,674**	**4,537**	**4,708**	**1**	**0**
National Science Foundation	**1,827**	**1,523**	**1,471**	**1,353**	**1,346**	**1,203**	**1,062**	**975**	**9**	**9**
Agriculture	**987**	**1,020**	**948**	**929**	**943**	**866**	**848**	**797**	**2**	**4**
Agricultural Research Service	529	513	479	463	470	451	443	405	3	3
Cooperative State Research Service	256	296	271	269	284	236	232	219	1	4
Forest Service	129	136	127	113	113	108	108	112	−2	2
Interior	**376**	**420**	**404**	**385**	**392**	**411**	**383**	**381**	**5**	**1**
Geological Survey[b]	222	236	227	219	215	209	157	153	4	8
Environmental Protection Agency	**374**	**350**	**348**	**317**	**320**	**261**	**241**	**335**	**10**	**1**
Commerce	**308**	**411**	**402**	**399**	**399**	**358**	**335**	**336**	**1**	**4**
National Oceanic & Atmospheric Administration	176	282	286	275	270	244	222	222	4	5
National Institute of Standards & Technology	118	111	99	101	101	96	95	89	−2	2
Others	**1,306**	**1,253**	**1,298**	**1,325**	**1,367**	**1,427**	**1,300**	**1,258**	**−2**	**1**
TOTAL	**$60,323**	**$58,512**	**$55,255**	**$51,412**	**$48,332**	**$42,225**	**$38,712**	**$36,433**	**7%**	**9%**
ANNUAL CHANGE	**3%**	**6%**	**7%**	**6%**	**14%**	**9%**	**6%**	**6%**		

Note: Fiscal years. a Estimated. b Includes Office of Water Research & Technology. Source: National Science Foundation

PERFORMERS OF FEDERALLY FUNDED R&D: Universities' share of total is growing

Federal obligations, $ millions	1989[a]	1988[a]	1987	1986	1985	1984	1983	1982	Annual change 1986–87	Annual change 1982–87
Industry	$31,107	$30,121	$28,612	$26,206	$23,760	$20,362	$18,649	$18,699	9%	9%
FFRDCs[b] administered by industry	1,923	1,888	1,860	1,697	1,791	1,608	1,501	1,506	10	4
Federal intramural programs	14,745	14,514	13,413	13,533	12,998	11,572	10,582	9,141	−1	8
Universities and colleges	11,805	11,142	10,563	9,019	8,892	7,890	7,232	6,582	17	10
FFRDCs[b] administered by universities	3,638	3,371	3,210	2,440	2,535	2,325	2,266	1,977	32	10
Nonprofit institutions	2,234	2,315	2,221	2,228	2,388	2,094	1,823	1,612	0	7
FFRDCs[b] administered by nonprofit institutions	528	514	511	553	689	597	581	521	−8	0
Foreign	290	272	298	296	245	176	240	214	0	7
State and local governments	142	148	148	126	129	131	186	184	15	−4
TOTAL	$60,323	$58,512	$55,255	$51,412	$48,360	$42,225	$38,712	$38,433	7%	9%

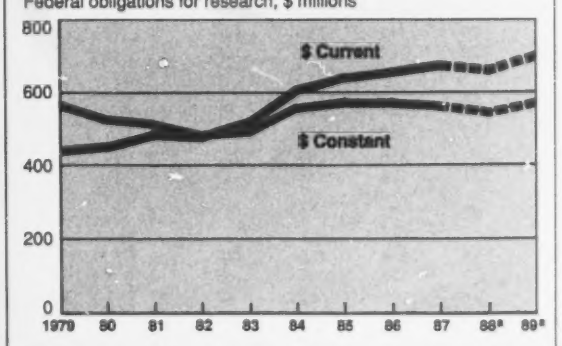
Note: Fiscal years. a Estimated. b Federally funded R&D centers. **Source:** National Science Foundation

FEDERAL OBLIGATIONS FOR SCIENTIFIC DISCIPLINES: Small gain for chemistry

$ Millions for research only	1989[a]	1988[a]	1987	1986	1985	1984	1983	1982	Annual change 1986–87	Annual change 1982–87
Life sciences	$ 7,954	$ 7,809	$ 7,344	$ 6,464	$ 6,366	$ 5,636	$ 5,178	$ 4,746	14%	9%
Engineering	4,253	4,082	3,906	3,739	3,629	3,624	3,517	3,387	4	3
Chemical	187	245	216	246	254	145	145	95	−12	18
Metallurgy and materials	415	461	362	445	439	341	333	309	−19	3
National engineering centers	624	639	669	632	664	858	828	788[a]	6	−3
Physical sciences	3,707	3,387	3,253	3,069	3,044	2,969	2,891	2,500	8	5
Chemistry	705	677	680	662	645	606	520	481	3	7
Physics	2,112	1,940	1,854	1,806	1,820	1,836	1,855	1,611	3	3
Environmental sciences	1,691	1,631	1,512	1,482	1,404	1,276	1,251	1,148	2	6
Mathematical and computer sciences	787	682	641	615	578	440	419	350	4	13
Other sciences	1,321	1,273	1,288	1,133	1,110	1,034	997	891	14	6
TOTAL	$19,712	$18,864	$17,943	$16,502	$16,130	$14,979	$14,254	$13,022	9%	7%
ANNUAL CHANGE	4%	5%	9%	2%	8%	5%	9%	7%		

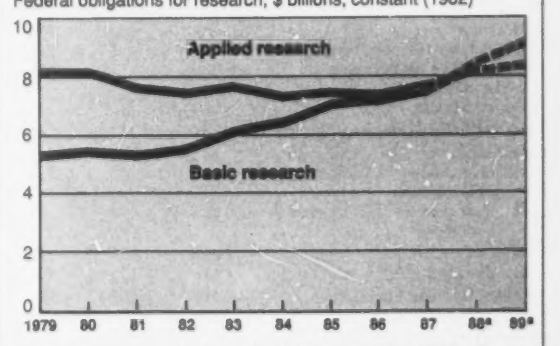
Note: Fiscal years. a Estimated. **Source:** National Science Foundation

Federal support for chemical research changed little in real terms since 1985



Note: Fiscal years. Constant-dollar values calculated by C&EN based on NSF data. a Estimated. **Source:** National Science Foundation

Funding for basic research has overtaken that for applied research



Note: Fiscal years. Constant-dollar values calculated by C&EN based on NSF data. a Estimated. **Source:** National Science Foundation

FEDERAL OBLIGATIONS FOR BASIC RESEARCH: Growth slows since early 1980s

$ Millions	1989[a]	1988[a]	1987	1986	1985	1984	1983	1982	Annual change 1986–87	Annual change 1982–87
Health & Human Services	$ 4,240	$4115	$3830	$3339	$3233	$2815	$2475	$2145	15%	12%
National Institutes of Health	3,964	3853	3577	3119	3018	2625	2313	2021	15	12
Alcohol, Drug Abuse & Mental Health Administration	255	241	232	203	197	171	145	117	14	15
National Science Foundation	1,708	1418	1371	1275	1262	1132	999	916	8	8
National Aeronautics & Space Administration	1,374	1229	1014	917	751	755	617	536	11	14
Energy	1,267	1194	1069	960	943	830	768	842	11	11
Defense	947	885	908	924	861	048	788	687	−2	6
Navy	357	342	354	337	343	316	305	280	5	5
Air Force	220	201	222	216	198	192	164	146	2	9
Army	176	166	217	248	241	222	208	188	−13	3
Defense agencies	194	176	115	122	79	118	108	73	−6	10
Agriculture	471	472	446	433	445	393	362	331	3	6
Agricultural Research Service	280	272	253	248	250	241	215	193	2	6
Cooperative State Research Service	132	139	133	132	142	100	99	91	1	8
Forest Service	49	52	49	42	44	41	39	39	17	5
Interior	122	135	135	133	138	126	103	77	1	12
Geological Survey[b]	87	89	85	83	81	79	65	53	2	10
Bureau of Mines	30	41	46	45	50	41	24	13[a]	2	29
Environmental Protection Agency	31	32	31	39	39	30	22	33	−21	−1
Commerce	27	28	26	27	23	21	19	17	−3	9
National Institute of Standards & Technology	26	27	25	26	22	20	18	17	−2	9
Others	114	117	116	107	124	119	109	99	8	3
TOTAL	$10,300	$9623	$8944	$8153	$7819	$7067	$6260	$5482	10%	10%
ANNUAL CHANGE	7%	8%	10%	4%	11%	13%	14%	14%		

Note: Fiscal years. a Estimated. Includes Office of Water Research & Technology. **Source:** National Science Foundation

FEDERAL OBLIGATIONS FOR APPLIED RESEARCH: Defense and health get nearly half

$ Millions	1989[a]	1988[a]	1987	1986	1985	1984	1983	1982	Annual change 1986–87	Annual change 1982–87
Defense	$2407	$2320	$2440	$2303	$2307	$2201	$2437	$2266	6%	1%
Army	595	547	693	579	583	487	485	452	20	9
Air Force	560	510	563	542	538	548	524	488	4	3
Navy	416	408	432	447	448	450	522	498	−3	−3
Defense agencies	836	854	751	735	738	717	906	828	2	−2
Health & Human Services	2273	2362	2195	1851	1796	1652	1545	1461	19	8
National Institutes of Health	1789	1883	1740	1469	1410	1286	1165	1104	18	10
Alcohol, Drug Abuse & Mental Health Administration	265	254	241	192	180	165	155	129	26	13
National Aeronautics & Space Administration	1700	1413	1256	1152	1033	955	928	871	9	8
Energy	959	1029	1029	1081	1198	1195	1193	1054	−5	0
Agriculture	485	517	473	464	466	442	456	436	2	2
Agricultural Research Service	222	215	201	188	192	184	203	186	7	2
Cooperative State Research Service	123	157	138	137	143	136	134	128	0	2
Forest Service	76	80	73	68	66	64	65	69	9	1
Environmental Protection Agency	261	243	246	179	176	142	152	211	37	3
Commerce	251	329	313	313	301	276	266	259	0	4
National Oceanic & Atmospheric Administration	159	240	234	237	224	198	189	189	−1	4
National Institute of Standards & Technology	82	74	64	63	65	64	63	57	1	2
Interior	232	260	247	235	231	254	255	275	5	−2
Geological Survey[b]	123	136	132	128	130	125	90	99	3	6
National Science Foundation	119	105	99	78	84	71	63	57	27	12
Others	727	663	700	693	720	725	699	651	1	1
TOTAL	$9412	$9241	$8999	$8349	$8312	$7911	$7993	$7541	8%	4%
ANNUAL CHANGE	2%	3%	8%	0%	5%	−1%	6%	5%		

Note: Fiscal years. a Estimated. b Includes Office of Water Research & Technology. **Source:** National Science Foundation

FEDERAL OBLIGATIONS FOR DEVELOPMENT: Defense's share holds steady at about 85%

$ Millions	1989[a]	1988[a]	1987	1986	1985	1984	1983	1982	Annual change 1986–87	Annual change 1982–87
Defense	$34,151	$33,338	$31,884	$29,711	$26,623	$22,324	$19,770	$17,700	7%	12%
Air Force	14,499	14,809	14,563	12,835	12,524	11,352	10,124	8,724	13	11
Navy	8,659	8,881	8,721	8,866	8,336	6,840	5,241	5,066	−2	11
Army	4,479	4,208	4,110	3,982	3,747	3,517	3,305	3,121	3	6
Defense agencies	6,216	5,213	4,354	3,911	1,965	557	1,039	717	11	43
Energy	2,956	2,878	2,659	2,648	2,825	2,649	2,576	3,012	0	−2
National Aeronautics & Space Administration	2,342	2,138	1,518	1,351	1,544	1,113	1,117	1,671	12	−2
Health & Human Services	531	636	584	468	423	365	332	335	25	12
National Institutes of Health	480	585	536	418	400	347	311	309	28	12
Environmental Protection Agency	83	76	71	100	106	89	66	92	−29	−5
Agriculture	31	31	29	32	32	31	30	31	−10	−1
Agricultural Research Service	26	26	24	27	28	27	26	26	−12	−1
Commerce	30	55	64	60	75	62	50	60	7	1
National Oceanic & Atmospheric Administration	17	42	52	37	45	47	33	34	39	9
National Institute of Standards & Technology	10	10	9	12	14	12	14	15	−20	−9
Interior	23	25	22	17	22	31	25	30	25	−6
Geological Survey[b]	12	11	10	7	4	5	2	1	38	83
National Science Foundation	0	0	0	0	0	0	0	2	—	—
Others	465	473	482	524	553	583	493	478	−8	0
TOTAL	$40,611	$39,648	$37,313	$34,910	$32,202	$27,246	$24,458	$23,410	7%	10%
ANNUAL CHANGE	2%	6%	7%	8%	18%	11%	4%	3%		

Note: Fiscal years. a Estimated. b Includes Office of Water Research & Technology. **Source:** National Science Foundation

ENGINEERING RESEARCH: NASA may edge out Pentagon as chief supporter of engineering research

Federal obligations, $ millions	1989[a] All engineering	1989[a] Chemical engineering	1989[a] Metallurgy & materials	1988[a] All engineering	1988[a] Chemical engineering	1988[a] Metallurgy & materials	1987 All engineering	1987 Chemical engineering
National Aeronautics & Space Administration	$1585.7	$ 1.7	$ 23.9	$1340.5	$ 1.7	$ 21.1	$1170.5	$ 1.5
Defense	1580.4	45.3	247.2	1600.9	47.3	292.8	1629.7	46.9
Air Force	457.4	3.2	31.8	416.9	6.4	17.3	460.3	1.8
Navy	385.0	21.6	54.7	378.4	20.6	54.2	401.5	21.3
Army	366.9	20.2	24.2	358.8	20.1	21.1	442.4	23.8
Defense agencies	371.2	0.3	136.5	446.9	0.3	200.2	325.6	0
Energy	351.0	55.3	81.0	455.8	117.4	83.2	442.2	88.9
National Science Foundation	237.9	44.2	27.2	202.0	39.2	24.8	191.7	37.3
Transportation	72.5	0.4	0.2	59.5	0.7	0.8	48.1	1.0
Interior	69.2	4.6	23.5	89.6	5.2	27.1	87.8	5.0
Environmental Protection Agency	53.1	24.3	0.8	50.6	24.0	0.5	55.4	25.6
Commerce	50.3	5.3	11.5	47.7	2.9	11.1	41.3	2.4
Agriculture	29.0	6.2	0	33.2	6.3	0	33.9	6.9
Others	223.3	0	0	202.3	0	0	205.8	0.3
TOTAL	$4252.5	$187.3	$415.4	$4082.1	$244.7	$461.3	$3906.2	$215.8
ANNUAL CHANGE	4%	−23%	−10%	5%	13%	27%	4%	−12%

Note: Fiscal years. a Estimated. **Source:** National Science Foundation

FEDERAL OBLIGATIONS FOR CHEMICAL RESEARCH: Funding stalls for energy and defense

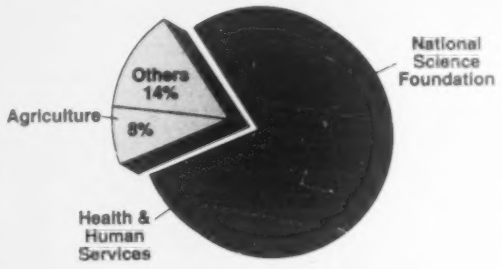
$ Millions	1989[a]	1988[a]	1987	1986	1985	1984	1983	1982	Annual change 1988–89	Annual change 1982–87
Energy	**$149.4**	**$157.4**	**$145.5**	**$145.9**	**$143.0**	**$140.4**	**$117.6**	**$105.4**	**0%**	**7%**
Defense	**130.2**	**118.2**	**144.9**	**163.4**	**156.4**	**139.8**	**121.8**	**118.1**	**−11**	**4**
Army	56.8	52.3	72.2	81.4	78.2	66.3	59.3	61.4	−11	3
Air Force	43.0	39.2	43.3	42.0	39.5	36.7	31.2	27.2	3	10
Navy	27.1	24.2	28.4	39.1	38.3	36.6	31.1	29.4	−27	−1
Defense agencies	3.2	2.5	1.1	0.9	0.4	0.3	0.3	0.3	28	30
Health & Human Services	**125.3**	**124.1**	**115.5**	**104.2**	**99.1**	**86.3**	**74.2**	**63.3**	**11**	**13**
National Institutes of Health	117.8	116.6	108.1	99.5	95.1	84.1	72.2	62.6	9	12
Alcohol, Drug Abuse & Mental Health Administration	7.5	7.5	7.4	4.7	4.0	2.3	2.0	1.2[a]	56	44
National Science Foundation	**137.8**	**116.7**	**115.3**	**112.6**	**115.6**	**109.9**	**92.4**	**86.1**	**2**	**6**
Agriculture	**59.0**	**60.2**	**65.0**	**58.6**	**58.0**	**69.0**	**63.8**	**58.5**	**11**	**2**
Agricultural Research Service	40.9	39.7	46.4	40.0	36.1	51.6	49.5	44.7	16	1
Cooperative State Research Service	10.8	12.9	11.5	12.4	16.1	13.5	10.8	10.2	−7	2
Forest Service	7.3	7.6	7.1	6.2	5.7	3.9	3.6	3.8[a]	14	13
Environmental Protection Agency	**34.5**	**33.3**	**34.6**	**20.1**	**17.5**	**15.9**	**14.8**	**18.8**	**72**	**13**
Commerce	**24.0**	**22.9**	**22.9**	**19.1**	**17.7**	**15.3**	**14.0**	**13.0**	**20**	**12**
National Institute of Standards & Technology	18.2	16.7	16.5	16.4	15.4	14.1	12.7	11.5	1	7
National Oceanic & Atmospheric Administration	5.8	6.2	6.4	2.4	1.4	1.3	1.2	0.9[a]	167	48
Interior	**20.0**	**22.0**	**20.9**	**20.3**	**19.4**	**19.2**	**6.2**	**6.2**	**3**	**27**
Geological Survey[b]	19.6	21.7	20.8	20.2	19.4	18.4	5.6	5.1	3	32
National Aeronautics & Space Administration	**17.8**	**15.4**	**13.4**	**11.8**	**16.3**	**7.3**	**9.4**	**6.2**	**13**	**17**
Others	**6.6**	**6.9**	**2.4**	**6.3**	**1.5**	**3.3**	**6.1**	**5.6**	**−63**	**−16**
TOTAL	**$704.6**	**$677.1**	**$680.3**	**$662.4**	**$644.5**	**$606.4**	**$520.3**	**$481.2**	**3%**	**7%**
ANNUAL CHANGE	**4%**	**0%**	**3%**	**3%**	**6%**	**17%**	**8%**	**−1%**		

Note: Fiscal years. a Estimated. b Includes Office of Water Research & Technology. **Source:** National Science Foundation

In 1989, but for chemical engineering 90% of funds come from Defense, Energy, NSF, and EPA

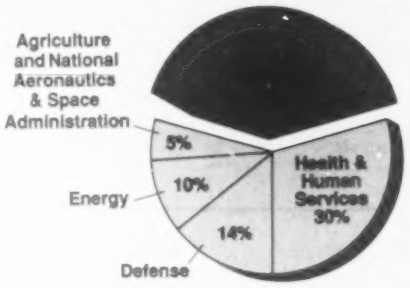
1987	1986			1985			1984		
Metallurgy & materials	All engineering	Chemical engineering	Metallurgy & materials	All engineering	Chemical engineering	Metallurgy & materials	All engineering	Chemical engineering	Metallurgy & materials
$ 19.9	**$1066.9**	**$ 1.0**	**$ 16.2**	**$ 931.6**	**$ 0.6**	**$ 15.8**	**$ 967.8**	**$ 0.3**	**$ 14.2**
203.6	**1505.6**	**50.3**	**253.7**	**1502.0**	**53.3**	**260.9**	**1488.4**	**38.4**	**180.3**
34.5	444.7	1.9	33.4	423.9	1.7	28.6	439.5	3.5	30.3
57.2	397.8	24.4	117.4	421.2	24.8	121.1	398.4	11.3	53.9
32.1	373.6	24.0	26.8	344.3	26.7	42.2	324.8	23.5	35.5
79.8	289.5	0	76.2	312.6	0.1	69.0	325.7	0.2	60.6
77.1	**494.2**	**121.6**	**82.6**	**511.3**	**136.6**	**68.4**	**439.0**	**46.1**	**68.7**
22.9	**199.1**	**33.4**	**43.5**	**193.3**	**32.6**	**42.7**	**164.9**	**27.7**	**27.3**
0.7	**52.8**	**1.9**	**1.8**	**49.4**	**0.6**	**1.5**	**51.1**	**1.2**	**1.9**
28.5	**93.2**	**4.7**	**38.5**	**100.2**	**4.8**	**39.8**	**111.4**	**4.5**	**42.2**
0.5	**48.6**	**23.9**	**0.5**	**44.8**	**18.0**	**2.6**	**37.8**	**17.8**	**0**
8.8	**41.7**	**2.6**	**7.6**	**39.8**	**1.7**	**6.9**	**35.3**	**1.8**	**6.4**
0	**31.1**	**6.0**	**0**	**28.7**	**5.8**	**0**	**56.7**	**6.4**	**0**
0.2	**205.9**	**0.4**	**0.5**	**227.4**	**0.3**	**0.5**	**271.7**	**0.3**	**0.1**
$362.0	**$3736.9**	**$245.8**	**$445.0**	**$3628.5**	**$254.1**	**$439.1**	**$3624.1**	**$144.5**	**$341.1**
−19%	**3%**	**−3%**	**1%**	**0%**	**76%**	**29%**	**3%**	**0%**	**3%**

Four agencies each provide about a fifth of federal funds for all chemical research . . .



Estimated fiscal 1989 federal chemistry research obligations = $705 million

. . . but NSF clearly dominates support for chemical research at universities



Estimated fiscal 1989 federal chemistry university research obligations = $315 million[a]

a Total is for these six agencies only. **Source:** National Science Foundation

UNIVERSITY RESEARCH: Overall growth has outpaced that for chemistry

Federal obligations, $ millions	1989[a]	1988[a]	1987	1986	1985	1984	1983	1982	Annual change 1986–87	Annual change 1982–87
Life sciences	**$4233**	**$4072**	**$3824**	**$3252**	**$3192**	**$2800**	**$2460**	**$2205**	**18%**	**12%**
Physical sciences	**955**	**852**	**823**	**752**	**750**	**698**	**597**	**559**	**9**	**8**
Chemistry	315	291	281	266	267	242	206	190	6	8
Physics	460	418	404	405	402	375	329	306	0	6
Engineering	**679**	**685**	**600**	**609**	**507**	**474**	**409**	**362**	**−2**	**11**
Chemical	51	60	55	51	46	51	24	19	7	23
Metallurgy and materials	156	176	108	133	107	88	86	75	−19	7
Environmental sciences	**462**	**412**	**400**	**366**	**361**	**320**	**317**	**275**	**9**	**8**
Mathematical and computer sciences	**397**	**319**	**289**	**274**	**253**	**182**	**172**	**140**	**5**	**16**
Other sciences	**479**	**460**	**449**	**365**	**348**	**304**	**298**	**256**	**23**	**12**
TOTAL	**$7205**	**$6802**	**$6384**	**$5617**	**$5411**	**$4777**	**$4252**	**$3798**	**14%**	**11%**
ANNUAL CHANGE	**6%**	**7%**	**14%**	**4%**	**13%**	**12%**	**12%**	**2%**		

Note: Fiscal years. Includes funding only from six agencies that together represent approximately 97% of federal research support to universities. a Estimated. **Source:** National Science Foundation

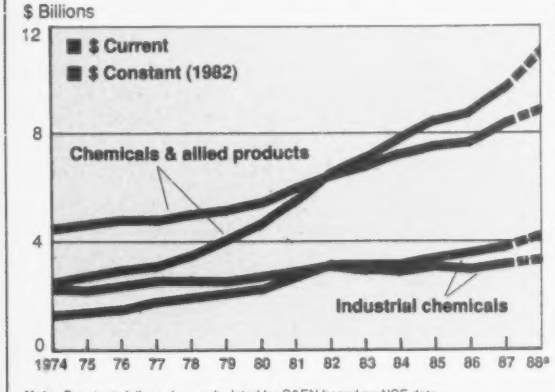
UNIVERSITY RESEARCH IN CHEMISTRY: Funding is dominated by NSF, NIH, and DOD

Federal obligations, $ millions	1989[a]	1988[a]	1987	1986	1985	1984	1983	Annual change 1986–87	Annual change 1983–87
National Science Foundation	**$128.1**	**$107.8**	**$107.1**	**$103.5**	**$108.1**	**$100.7**	**$ 84.7**	**4%**	**6%**
Health & Human Services	**94.1**	**91.0**	**85.0**	**75.0**	**75.2**	**63.2**	**51.9**	**13**	**13**
National Institutes of Health	92.5	89.4	83.4	74.4	74.7	62.8	51.4	12	13
Alcohol, Drug Abuse & Mental Health Administration	1.6	1.6	1.6	0.6	0.6	0.4	0.5	172	37
Defense	**45.1**	**42.4**	**45.0**	**43.2**	**40.4**	**34.7**	**29.1**	**4**	**11**
Air Force	18.2	16.6	18.4	16.1	14.0	na	9.6	14	18
Navy	17.1	16.3	17.2	13.9	15.5	na	11.7	24	10
Army	6.5	7.0	8.3	12.4	10.9	na	7.8	−33	1
Defense agencies	3.2	2.5	1.1	0.9	0	na	0	28	—
Energy	**32.0**	**32.6**	**28.5**	**27.6**	**26.0**	**26.3**	**18.6**	**3**	**11**
Agriculture	**10.6**	**12.6**	**11.2**	**12.2**	**15.5**	**13.5**	**14.5**	**−8**	**− 6**
National Aeronautics & Space Administration	**4.9**	**4.8**	**4.3**	**4.2**	**4.1**	**4.1**	**4.6**	**2**	**− 2**
TOTAL	**$314.8**	**$291.3**	**$281.1**	**$265.7**	**$269.4**	**$242.3**	**$205.7**	**6%**	**8%**
ANNUAL CHANGE	**8%**	**4%**	**6%**	**−1%**	**11%**	**18%**	**na**		

Note: Fiscal years. Data from these six agencies represent approximately 97% of federal obligations for 1989. a Estimated. na = not available. **Source:** National Science Foundation

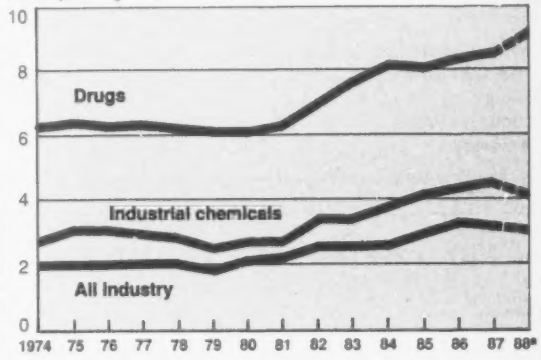
Strong Drug Company R&D Sets Pace

R&D spending for all chemicals has outpaced inflation for over a decade



Note: Constant-dollar values calculated by C&EN based on NSF data.
a C&EN estimates. **Source:** National Science Foundation

Drug firms continue growth in share of revenue supporting R&D



a C&EN estimates. **Source:** National Science Foundation

TOTAL FUNDS FOR INDUSTRIAL R&D: Chemical industry R&D topped $10 billion last year

$ Millions	1988a	1987	1986	1985	1984	1983	1982	1981	1980	1979	1978	1977	Annual change 1986–87	Annual change 1977–87
Chemicals and allied products	$ 11,000	$ 9,831	$ 8,837	$ 8,540	$ 7,927	$ 7,185	$ 6,604	$ 5,625	$ 4,636	$ 4,038	$ 3,580	$ 3,202	11%	12%
Industrial chemicals	4,200	3,879	3,552	3,498	3,240	3,214	3,206	2,602	2,197	1,962	1,798	1,668	9	9
Drugs	4,800	4,091a	3,656	3,490a	3,316a	2,901a	2,481a	2,073a	1,777a	1,517	1,308	1,117	12	14
Other chemicals	2,000	1,861a	1,628	1,552a	1,371a	1,070a	917a	750a	662a	559	474	417	14	16
Other industries	**91,000**	**86,474**	**81,059**	**77,070**	**68,160**	**$58,509**	**52,406**	**46,185**	**39,869**	**34,188**	**29,724**	**26,623**	**7**	**13**
TOTAL	**$102,000**	**$96,305**	**$89,896**	**$85,610**	**$76,087**	**$65,694**	**$59,010**	**$51,810**	**$44,505**	**$38,226**	**$33,304**	**$29,825**	**7%**	**12%**

a C&EN estimates. **Source:** National Science Foundation

COMPANY FUNDS FOR INDUSTRIAL R&D: Strong rebound in 1987 after slow growth in 1986

$ Millions	1987	1986	1985	1984	1983	1982	1981	1980	1979	1978	1977	Annual change 1986–87	Annual change 1977–87
Chemicals and allied products	$ 9,638	$ 8,656	$ 8,310	$ 7,736	$ 6,792	$ 6,197	$ 5,205	$ 4,264	$ 3,692	$ 3,250	$ 2,907	11%	13%
Industrial chemicals	3,691	3,374	3,281	3,057	2,828	2,810	2,393	1,856	1,617	1,473	1,387	9	10
Drugs	4,088	3,654	3,481	3,310	2,896	2,473	2,064	1,756	1,516a	1,304a	1,107a	12	14
Other chemicals	1,859	1,628	1,548	1,369	1,068	914	747	653	559a	473a	413a	14	16
Other industries	**55,264**	**53,069**	**50,170**	**44,995**	**38,245**	**34,279**	**30,223**	**26,212**	**22,016**	**18,865**	**16,433**	**4**	**13**
TOTAL	**$64,902**	**$61,725**	**$58,480**	**$52,731**	**$45,037**	**$40,476**	**$35,428**	**$30,476**	**$25,708**	**$22,115**	**$19,340**	**5%**	**13%**

a C&EN estimates. **Source:** National Science Foundation

FEDERAL FUNDS FOR INDUSTRIAL R&D: Modest as usual for chemicals but up a bit in 1987

$ Millions	1987	1986	1985	1984	1983	1982	1981	1980	1979	1978	1977	Annual change 1986–87	Annual change 1977–87
Chemicals and allied products	$ 193	$ 181	$ 230	$ 191[a]	$ 393	$ 407	$ 421	$ 372	$ 346	$ 330	$ 295	7%	−4%[a]
Industrial chemicals	188	179	217	183[a]	386	396	409	341	345	325	281	5	−4[a]
Drugs and other chemicals	5	2	13	8	7	11	12	31	1	5	14	—	—
Other industries	31,210	27,990	26,900	23,165	20,264	18,127	15,961	13,657	12,172	10,859	10,190	12	12
TOTAL	$31,403	$28,171	$27,130	$23,356	$20,657	$18,534	$16,382	$14,029	$12,518	$11,189	$10,485	11%	12%

a The decline in 1984 from 1983 results from the administration of federally funded Oak Ridge National Laboratory being changed from a chemical company to a company in the aircraft and missile industry. **Source:** National Science Foundation

COST PER INDUSTRIAL R&D SCIENTIST OR ENGINEER: Chemicals catch up with all industry

$ Thousands	1987	1986	1985	1984	1983	1982	1981	1980	1979	1978	1977
Chemicals and allied products	$132.9	$118.8	$116.3	$112.5	$104.8	$102.5	$ 96.6	$ 87.4	$79.6	$72.8	$67.6
Industrial chemicals	163.0	114.1	114.6	132.0	123.1	122.1	118.0	103.4	92.8	84.2	79.6
Drugs	a	119.9	a	a	103.1	a	a	79.2	71.4	64.8	59.9
Other chemicals	a	84.6	a	a	a	a	a	66.5	66.5	61.6	53.8
All industry	$132.7	$130.3	$131.4	$125.5	$116.4	$112.2	$103.9	$ 94.9	$87.4	$80.4	$75.8

a Not separately available but included in chemicals and allied products. **Source:** National Science Foundation

R&D BY U.S. COMPANIES ABROAD: Chemical companies substantially boost foreign R&D

$ Millions	1987	1986	1985	1984	1983	1982	1981	1980	1979	1978	1977	Annual change 1986–87	Annual change 1977–87
Chemicals and allied products	$1265	$1071	$ 843	$ 786	$ 729	$ 682	$ 715	$ 603	$ 500	$ 395	$ 332	18%	14%
Industrial and other chemicals	684	579	444	385	368	319	287	246	199	151	133	18	18
Drugs	581	492	399	401	361	363	428	357	301	244	199	18	11
Other industries	3756	3580	2807	2847	2540	2412	2679	2562	2254	1814	1545	5	9
TOTAL	$5021	$4651	$3650	$3633	$3269	$3094	$3393	$3165	$2754	$2209	$1877	8%	10%

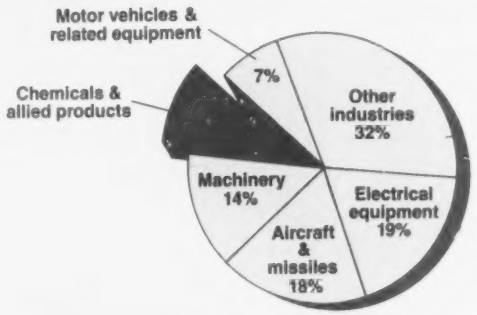
Source: National Science Foundation

CHEMICAL R&D SPENDING: Biggest programs got biggest boosts in 1988

$ Millions	1988	1987	1986	1985	1984	1983	1982	1981	1980	1979	1978	1988 R&D spending as % of sales
Du Pont	$1319	$1223	$1156	$1144	$1097	$ 966	$ 879	$ 718	$ 591	$ 509	$ 461	4.0%
Dow Chemical	772	670	605	547	507	492	460	404	314	269	232	4.6
Monsanto	648	615	596	470	370	290	264	233	208	161	136	7.8
American Cyanamid	365	314	278	251	232	208	185	166	148	130	108	7.9
Union Carbide[a]	159	159	148	275	265	245	240	207	166	161	156	1.9
Rohm & Haas	156	142	133	124	109	100	92	77	67	54	49	6.2
W. R. Grace	119	107	94	92	81	73	64	57	45	42	37	2.1
Hercules	74	74	71	76	72	74	74	65	57	50	43	2.6
Lubrizol	65	62	51	44	33	37	36	33	28	23	21	5.8
Olin	58	62	56	53	52	49	45	38	31	26	25	2.5
Air Products	72	57	61	51	44	40	37	32	30	24	23	3.0
Ethyl	59	50	47	47	40	39	39	37	34	29	25	2.9
International Flavors	50	45	39	34	32	32	31	30	29	27	24	6.0
Nalco Chemical	37	35	33	32	32	30	33	30	28	21	17	3.7
Pennwalt	31	45	45	39	36	33	31	27	24	22	23	3.0
TOTAL	$3984	$3660	$3413	$3279	$3002	$2708	$2510	$2154	$1800	$1548	$1380	4.3%
ANNUAL CHANGE	9%	7%	4%	9%	11%	8%	17%	20%	16%	12%	13%	

Note: Prior years not restated to reflect company revisions. a Union Carbide divested a substantial part of its business in 1986; on a pro forma basis, R&D spending was $181 million in 1985 and $178 million in 1984. **Source:** Company data

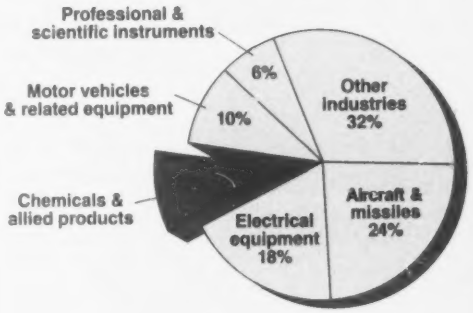
One tenth of scientists and engineers in industry work for chemical companies...



1988 total industrial R&D scientists and engineers[a] = 725,800

a Full-time equivalent as of January 1988. **Source:** National Science Foundation

...and those companies perform a tenth of all industrial R&D in the U.S.



1988 total industrial R&D expenditures = $96.3 million

R&D SCIENTISTS AND ENGINEERS IN INDUSTRY: Industrial chemical firms show decline

Thousands	1988	1987	1986	1985	1984	1983	1982	1981	1980	1979	1978	Annual change 1987–88	Annual change 1978–88
Chemicals and allied products	**74.9**	**73.0**	**75.8**	**71.1**	**69.8**	**67.3**	**61.6**	**54.7**	**51.4**	**50.0**	**48.3**	**3%**	**4%**
Industrial chemicals	23.2[a]	24.4	24.9	23 5	25.6	26.6	25.9	21.6	20.9	21.4	21.3	−5	1
Drugs	31.2	29.2	31.8	30.8	30.8[a]	28.2	25.6	23.3	21.6	20.8	19.5	7	5
Other chemicals	20.5	19.4	19.1	16.7	13.4	12.1	10.1	9.8	8.9	7.8	7.5	6	11
Other industries	**650.9**	**630.8**	**600.7**	**555.1**	**516.7**	**474.6**	**448.2**	**433.1**	**399.2**	**373.9**	**356.1**	**3**	**6**
TOTAL	**725.8**	**703.8**	**676.5**	**626.2**	**586.5**	**541.9**	**509.8**	**487.8**	**450.6**	**423.9**	**404.4**	**3%**	**6%**

Note: Data as of January of each year for full-time-equivalent personnel. a C&EN estimates. **Source:** National Science Foundation

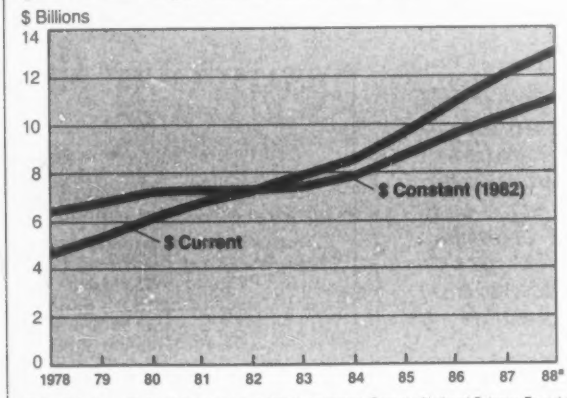
CHEMISTS IN INDUSTRY: 40% work in pharmaceutical, specialty, or basic chemical firms

Industry	% of industrial chemists: All chemists	B.S.	M.S.	Ph.D.	Mean salary ($ thousands)[a]: B.S	M.S.	Ph.D.
Pharmaceuticals[b]	18%	16%	21%	19%	$42.4	$50.7	$64.9
Specialty chemicals	15	15	14	16	45.7	51.3	61.6
Basic chemicals	7	4	5	9	46.3	50.0	64.6
Plastics	6	6	5	7	46.2	52.2	64.2
Electronics	5	4	5	5	46.2	52.5	62.2
Petroleum and natural gas	4	4	3	5	44.4	56.3	69.5
Food	4	5	4	3	41.5	49.6	59.9
Coatings	4	6	4	3	41.6	48.5	56.3
Agricultural chemicals	3	3	3	4	37.5	47.3	62.2
Metals and minerals	2	3	3	1	39.6	46.1	56.1
Biochemical products	2	1	2	3	38.7	52.7	61.1
Rubber	2	2	1	1	45.5	50.8	57.1
Soaps and detergents	1	2	1	1	39.4	53.4	57.3
Paper	1	1	1	1	41.8	44.7	54.4
Other manufacturing	15	15	16	14	42.1	50.5	58.9
Nonmanufacturing	10	14	12	7	39.0	48.2	61.2

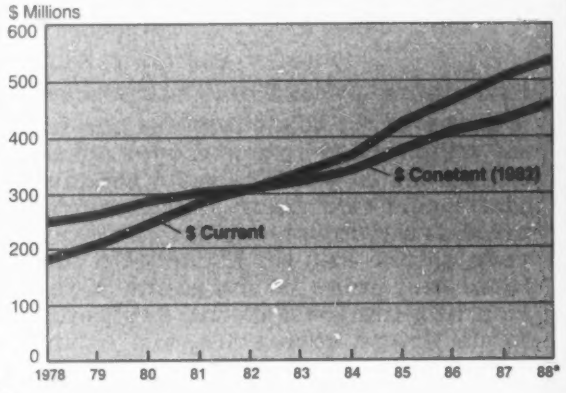
a As of March 1, 1989; to facilitate comparison, mean salaries are adjusted for differences in average length of experience for each group. b Includes personal care products. **Source:** ACS survey

Universities Fastest Growing R&D Sector

Funding for R&D at universities has grown strongly in recent years...



...and for chemical R&D as well, even when inflation is taken into account



Note: Data for institutional fiscal years. a C&EN estimates. Source: National Science Foundation

CHARACTER OF UNIVERSITY R&D SPENDING: Nearly 70% goes for basic research

$ Millions	1987	1986	1985	1984	1983	1982	1981	1980	1979	1978a	1977	Annual change 1986–87	Annual change 1977–87
Basic research	$ 8,301	$ 7,512	$6556	$5731	$5324	$4883	$4589	$4024	$3612	$3176	$2800	11%	11%
Applied research	3,125b	2,828b	2584b	2413b	2119b	2023b	1877b	1693b	1465	1213	1067	11	11
Development	655b	586b	554b	479b	440b	418b	379b	344b	284	236	200	12	13
TOTAL	$12,082	$10,926	$9695	$8623	$7884	$7324	$6845	$6062	$5361	$4625	$4067	11%	12%
ANNUAL CHANGE	11%	13%	12%	9%	8%	7%	13%	13%	16%	14%	9%		

Note: Data for institutional fiscal years. Data since 1980 were revised in 1987. a NSF estimates, based on data from Ph.D.-granting institutions only. b C&EN estimates.
Source: National Science Foundation

SOURCE OF UNIVERSITY R&D FUNDS: Schools' own funds support 18% of R&D effort

$ Millions	1987	1986	1985	1984	1983	1982	1981	1980	1979	1978a	1977	Annual change 1986–87	Annual change 1977–87
Federal government	$ 7,326	$ 6,713	$6064	$5425	$4980	$4759	$4561	$4096	$3595	$3059	$2726	9%	10%
Institutional funds	2,126	1,877	1632	1424	1315	1122	1009	835	728	623	514	13	15
State and local governments	1,019	911	745	684	622	613	546	491	470	414	374	12	11
Industry	777	692	559	474	388	339	293	238	194	170	139	12	19
Other sources	834	732	694	617	579	491	436	401	374	359	314	14	10
TOTAL	$12,082	$10,926	$9695	$8623	$7884	$7324	$6845	$6062	$5361	$4625	$4067	11%	12%

Note: Data for institutional fiscal years. Data since 1980 were revised in 1987. a NSF estimates, based on data from Ph.D.-granting institutions only. Source: National Science Foundation

FIELDS OF UNIVERSITY R&D SPENDING: Support for science R&D tops $10 billion in 1987

$ Millions	1987	1986	1985	1984	1983	1982	1981	1980	1979	1978[a]	1977	Annual change 1986–87	Annual change 1977–87
All sciences	**$10,193**	**$ 9,284**	**$8275**	**$7400**	**$6761**	**$6291**	**$5877**	**$5196**	**$4593**	**$4024**	**$3569**	**10%**	**11%**
Life	6,478	5,895	5278	4716	4308	4015	3695	3218	2833	2538	2259	10	11
Physical	1,379	1,282	1148	996	901	824	767	678	602	469	424	8	13
Physics	658	628	550	471	417	367	357	322	292	235	202	5	13
Chemistry	508	468	422	370	336	309	286	245	206	183	159	8	12
Environmental	832	780	709	651	618	559	550	509	453	379	319	7	10
Psychology and social	684	628	545	511	486	490	499	453	396	367	353	9	7
Computer	370	318	281	224	176	149	133	114	98	67	56	16	21
Mathematical	180	153	130	125	108	98	89	79	79	59	52	18	13
Others	268	227	185	178	165	156	145	146	134	117	106	18	10
Engineering	**1,889**	**1,642**	**1419**	**1223**	**1122**	**1033**	**968**	**866**	**768**	**601**	**499**	**15**	**14**
Chemical	140	126	109	95	91	83	84	68	na	na	na	12	—
TOTAL	**$12,082**	**$10,926**	**$9695**	**$8623**	**$7884**	**$7324**	**$6845**	**$6062**	**$5361**	**$4625**	**$4067**	**11%**	**12%**
ANNUAL CHANGE	**11%**	**13%**	**12%**	**9%**	**8%**	**7%**	**13%**	**13%**	**15%**	**14%**	**9%**		

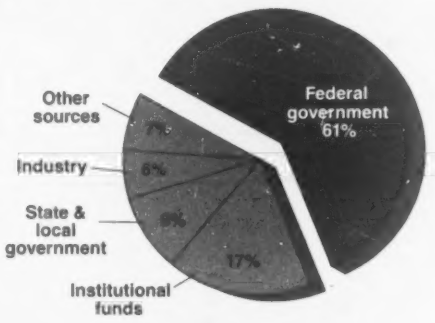
Note: Data for institutional fiscal years. Data since 1980 were revised in 1987. a NSF estimates, based on data from Ph.D.-granting institutions only. na = not available.
Source: National Science Foundation

FEDERALLY FINANCED R&D SPENDING AT UNIVERSITIES: Slower growth for chemistry

$ Millions	1987	1986	1985	1984	1983	1982	1981	1980	1979	1978[a]	1977	Annual change 1986–87	Annual change 1977–87
All sciences	**$6214**	**$5733**	**$5196**	**$4643**	**$4241**	**$4062**	**$3899**	**$3500**	**$3069**	**$2651**	**$2389**	**8%**	**10%**
Life	3826	3498	3188	2831	2587	2503	2365	2094	1819	1626	1474	9	10
Physical	1041	983	890	780	700	649	619	555	491	392	339	6	12
Physics	526	511	453	390	342	306	309	280	253	199	172	3	12
Chemistry	365	339	312	278	248	230	217	190	157	138	122	8	12
Environmental	546	521	478	451	427	392	392	372	329	275	239	5	9
Psychology and social	291	281	260	241	236	250	280	263	227	204	202	3	4
Computer	253	229	193	161	128	107	93	77	69	41	38	10	21
Mathematical	131	113	96	91	76	72	68	61	60	44	41	16	12
Others	126	108	91	87	87	88	82	78	73	68	58	17	8
Engineering	**1112**	**980**	**869**	**782**	**739**	**698**	**663**	**596**	**526**	**408**	**337**	**13**	**13**
Chemical	70	67	58	54	52	50	56	46	na	na	na	5	—
TOTAL	**$7326**	**$6713**	**$6064**	**$5425**	**$4980**	**$4759**	**$4561**	**$4096**	**$3595**	**$3059**	**$2726**	**9%**	**10%**
ANNUAL CHANGE	**9%**	**11%**	**12%**	**9%**	**5%**	**4%**	**11%**	**14%**	**18%**	**12%**	**9%**		

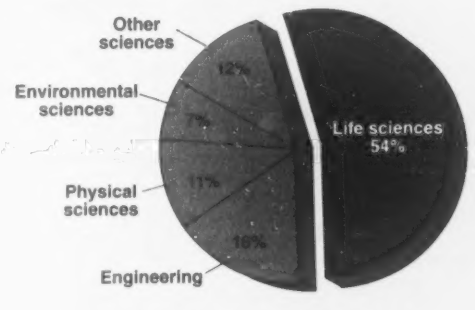
Note: Data for institutional fiscal years. Data since 1980 were revised in 1987. a NSF estimates, based on data from Ph.D.-granting institutions only. na = not available.
Source: National Science Foundation

Three fifths of academic R&D support comes from the federal government...



Fiscal 1987 academic R&D expenditures = $12.1 billion

...and more than half is spent in the life sciences



Fiscal 1987 academic R&D expenditures = $12.1 billion

Source: National Science Foundation

TOP 10 UNIVERSITY R&D CENTERS: Los Alamos spends most on physical sciences R&D

$ Millions, fiscal 1987	Physical sciences	Engineering	Math & computer sciences	Environmental sciences	Life sciences	Psychology & social sciences	Other sciences	Total
1 Jet Propulsion Lab	$ 107.3	$ 388.7	$329.6	$ 89.9	$ 0	$ 0	$0	$ 915.5
2 Lawrence Livermore Lab	271.8	457.8	129.4	30.3	25.5	0	0	914.8
3 Los Alamos National Lab	405.3	283.3	77.9	21.0	27.2	17.8	2.8[a]	835.3
4 Lincoln Lab	67.9	249.7	35.7	0	0	0.4	0	353.7
5 Argonne National Lab	86.5	130.7	4.1	43.2	12.0	0	0	276.6
6 Brookhaven National Lab	156.1	33.7	0.8	9.2	18.7	2.0	0	220.5
7 Lawrence Berkeley Lab	105.6	16.8	5.6	18.0	30.6	0	1.4	178.1
8 Fermi National Accelerator Lab	164.5	0	0	0	2.6	0	0	167.1
9 Plasma Physics Lab	107.2	0	0	0	0	0	0	107.2
10 Stanford Linear Accelerator Center	89.0	0	0	0	0	0	0	89.0
All others	69.2	3.0	14.2	50.1	5.5	2.1	0	144.1
TOTAL, ALL FEDERALLY FUNDED R&D CENTERS	$1630.5	$1563.8	$597.2	$261.7	$122.3	$22.3	$4.2	$4202.0

Note: Data for university-administered, federally funded R&D centers. A number of institutions have developed or are in the process of developing new computer systems and methodologies that enable them to report more accurately the total cost of science and engineering research. Fiscal 1986 comparisons with data reported in earlier years may be inappropriate in some areas. a Estimated. **Source:** National Science Foundation

CAPITAL SPENDING AT UNIVERSITIES: Physical sciences get strong federal support

$ Millions	1987 Total spending	1987 % federal funds	1986	1985	1984	1983	1982	Annual change 1986–87	Annual change 1982–87
All sciences	$1390.6	9%	$1206.9	$1067.6	$1069.9	$ 962.1	$824.7	15%	11%
Life sciences	944.6	6	797.5	712.3	740.8	678.4	590.4	18	10
Physical sciences	156.1	23	142.4	119.6	114.7	96.8	82.1	10	14
Mathematical and computer sciences	81.4	12	89.6	76.8	49.6	52.9	34.3	−9	19
Psychology and social sciences	66.1	6	69.2	75.7	87.1	57.4	43.6	−4	9
Environmental sciences	51.5	23	46.8	53.8	36.7	41.0	42.4	10	4
Other sciences	91.0	14	61.5	29.4	41.0	35.7	31.9	48	23
Engineering	389.2	10	309.9	182.4	142.0	134.5	144.5	26	22
TOTAL	$1779.8	9%	$1516.8	$1249.9	$1211.8	$1096.6	$969.1	17%	13%
ANNUAL CHANGE	17%	—	21%	3%	11%	13%	20%		

Note: Data for institutional fiscal years. Includes expenditures for facilities and equipment for research, development, and instruction. **Source:** National Science Foundation

UNIVERSITY SPENDING FOR RESEARCH EQUIPMENT: Growing strongly for chemistry

$ Millions	1987 Total	1987 Federal funds	1986 Total	1986 Federal funds	1980 Total	1980 Federal funds	Annual change 1986–87 Total	Annual change 1986–87 Federal funds	Annual change 1980–87 Total	Annual change 1980–87 Federal funds
All sciences	$660.5	$425.1	$636.2	$420.1	$277.8	$185.1	4%	1%	19%	18%
Life sciences	333.6	187.9	327.6	187.2	170.0	109.1	2	0	14	11
Physical sciences	164.5	129.7	163.0	131.5	54.0	44.4	1	−1	25	24
Physics	79.2	65.6	89.3	76.8	25.6	22.7	−11	−15	25	24
Chemistry	66.6	49.5	59.7	44.3	23.6	18.1	12	12	23	22
Mathematical and computer sciences	56.8	45.6	51.5	42.7	9.8	4.8	10	7	42	59
Environmental sciences	56.1	36.7	52.5	36.8	24.5	16.2	7	0	18	18
Other sciences	49.5	25.8	41.7	21.8	19.6	10.8	19	18	20	19
Engineering	172.0	99.1	142.2	82.1	55.6	35.0	21	21	25	23
Chemical	14.5	7.5	13.2	7.4	4.7	2.8	10	1	25	21
TOTAL	$832.5	$524.7	$778.3	$502.2	$333.5	$220.1	7%	4%	20%	19%

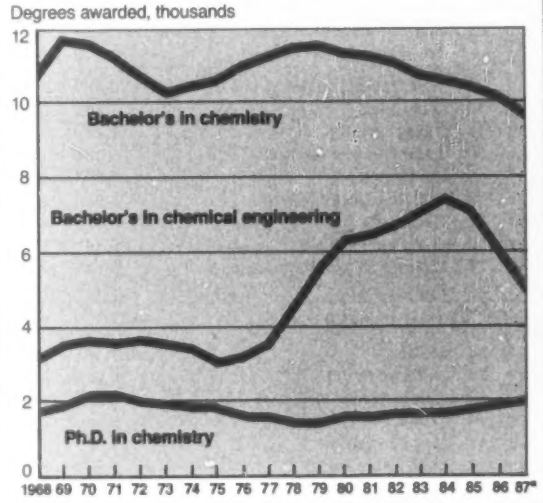
Note: Data for institutional fiscal years. **Source:** National Science Foundation

CHEMICAL DEGREES: Bachelor's degrees in chemistry set 20-year low

Academic year	Degrees awarded in chemistry			Degrees awarded in chemical engineering		
	Bachelor's	Master's	Ph.D.	Bachelor's	Master's	Ph.D.
1968	10,847	2014	1757	3211	1156	367
1969	11,807	2070	1941	3557	1136	409
1970	11,617	2146	2208	3720	1045	438
1971	11,183	2284	2160	3615	1100	406
1972	10,721	2259	1971	3663	1154	394
1973	10,226	2230	1882	3636	1051	397
1974	10,525	2138	1828	3454	1045	400
1975	10,649	2006	1824	3142	990	346
1976	11,107	1796	1623	3203	1031	308
1977	11,322	1775	1571	3581	1086	291
1978	11,474	1892	1525	4615	1237	259
1979	11,643	1765	1518	5655	1149	304
1980	11,446	1733	1551	6383	1271	284
1981	11,347	1654	1622	6527	1267	300
1982	11,062	1751	1722	6740	1285	311
1983	10,746	1604	1746	7145	1304	319
1984	10,704	1667	1744	7475	1514	330
1985	10,482	1719	1789	7146	1544	418
1986	10,116	1754	1908	5877	1361	446
1987[a]	9,661	1738	1976	4983	1184	497

a Preliminary figures. **Source:** National Center for Education Statistics

Only Ph.D. degrees are increasing



Note: Academic years. a Preliminary figures.
Source: National Center for Education Statistics

TOP 10 UNIVERSITIES IN R&D SPENDING: Johns Hopkins, MIT lead for physical sciences

$ Millions, fiscal 1987	Physical sciences	Chemistry[a]	Engineering	Environmental sciences	Life sciences	Math & computer sciences	Other sciences	Total
1 Johns Hopkins U	$ 79.4	$ 5.6	$ 172.8	$ 28.0	$ 136.2	$ 80.9	$ 13.7	$ 510.9
2 Massachusetts Institute of Technology	78.8	11.5	110.8	10.6	32.8	13.0	18.3	264.4
3 U of Wisconsin, Madison	25.4	7.0	30.1	19.6	144.7	7.2	27.6	254.5
4 Cornell U	41.3	8.1	35.1	5.9	134.4	16.3	11.8	244.8
5 Stanford U	45.1	8.9	68.0	4.3	103.1	15.0	5.4	240.9
6 U of Michigan	15.2	3.3	35.9	14.0	113.5	5.7	40.7	224.9
7 U of Minnesota	12.5	5.4	23.2	5.8	162.1	5.4	13.5	222.4
8 Texas A&M U	16.6	7.5	33.4	48.4	103.3	4.6	13.6	219.9
9 U of California, Los Angeles	20.9	10.1	19.9	11.6	107.5	6.9	21.9	188.8
10 U of Illinois, Urbana	21.8	9.0	51.8	21.3	42.9	17.0	33.9	188.7
TOTAL, FIRST 10 INSTITUTIONS	$ 356.9	$ 76.4	$ 581.0	$169.5	$1080.5	$171.9	$200.4	$ 2,560.2
TOTAL, ALL INSTITUTIONS	$1378.7	$507.8	$1888.7	$832.0	$6478.5	$550.8	$952.6	$12,081.5

Note: Data for institutional fiscal years. A number of institutions have developed or are in the process of developing new computer systems and methodologies that enable them to report more accurately the total cost of science and engineering research. Fiscal 1987 comparisons with data reported in earlier years may be inappropriate in some areas. a Included in physical sciences.
Source: National Science Foundation

SCHOOLS SPENDING MOST ON CHEMICAL R&D: Five spent more than $10 million in 1987

Rank 1987	Rank 1986		1987 Total spending ($ thousands)	1987 % federal funds	1986	1985	1984	1983	1982	Annual change 1986–87	Annual change 1982–87
					($ thousands)						
1	3	U of California, Berkeley	$ 12,490	89%	$ 9,114	$ 10,804	$ 7,850	$ 7,945	$ 6,283	37%	15%
2	1	Massachusetts Inst. of Technology	11,471	93	13,593	13,221	11,741	8,914	9,792	−16	3
3	5	U of Texas, Austin	11,420	56	8,531	7,908	6,639	5,938	4,843	34	19
4	2	California Inst. of Technology	10,870	91	9,176	7,605	6,446	6,994	6,136	18	12
5	7	U of California, Los Angeles	10,099	93	7,954	7,243	7,219	5,496	5,187	27	14
6	8	U of Maryland, College Park	9,258	44	7,904	7,289	6,324	6,333[a]	4,718[a]	17	14
7	4	U of Illinois, Urbana	9,035	70	8,604	7,079	6,284	5,886	6,422	5	7
8	6	Stanford U	8,916	89	8,340	8,354	6,809	6,375	5,564	7	10
9	14	Harvard U	8,895	93	7,202	6,557[a]	6,307[a]	6,898[a]	5,512[a]	24	10
10	11	Cornell U	8,095	83	7,376	7,962	6,710	5,717[a]	6,239[a]	10	5
		Total, first 10 institutions	$100,549	80%	$ 87,794	$ 84,022	$ 72,329	$ 66,496	$ 60,696	15%	11%
11	15	U of Massachusetts, Amherst	7,589	66	6,967	6,420	6,347	5,162	4,364	9	12
12	10	U of Chicago	7,514	86	7,553[a]	6,921[a]	5,735	4,798	4,396	−1	11
13	13	Texas A&M U	7,462	54	7,230[a]	6,768[a]	5,606[a]	4,963	4,521	3	11
14	60	Case Western Reserve U	7,164	70	2,922[a]	2,802	2,759	2,232	2,185	145	27
15	19	Purdue U	7,092	84	6,315	6,018	5,443	4,542	4,459	12	10
16	9	U of Wisconsin, Madison	6,984	68	7,892	7,350	6,076	5,310	4,567	−12	9
17	12	Rockefeller U	6,823	48	7,335	4,826[a]	1,178	919	—	−7	—
18	22	U of Pennsylvania	6,741	84	6,064	5,025	4,375	4,982	3,068	11	17
19	25	Columbia U, main division	6,715	99	5,555	5,188	4,662	4,281	4,700	21	7
20	24	Princeton U	6,477	78	5,702	3,963	3,670	3,509	3,062	14	16
		Total, first 20 institutions	$171,110	78%	$151,329	$139,303	$118,180	$107,194	$ 96,018[b]	13%	12%
21	21	Indiana U	6,181	80	6,110	5,820	5,642	5,551	5,341	1	3
22	33	Northwestern U	6,095	76	4,826	5,062	4,557	3,413	3,026	26	15
23	18	Pennsylvania State U	6,072	81	6,438	6,509	5,124	4,729	3,564	−6	11
24	16	Ohio State U	5,755	78	6,546	5,422	4,104	3,739	2,907	−12	15
25	34	U of Florida	5,690	61	4,750	4,380	4,024	2,347	2,248	20	20
26	26	Johns Hopkins U	5,593	91	5,506	4,612[a]	4,030	4,592[a]	4,721	2	3
27	27	U of Notre Dame	5,550	93	5,402	5,549	4,760	4,022	4,020	3	7
28	20	Yale U	5,538	89	6,169[a]	5,600[a]	4,134	3,341	2,875	−10	14
29	30	U of Minnesota	5,426	81	5,110	4,167	4,067	4,047	4,297	6	5
30	17	U of California, San Diego	5,179	89	6,535	4,642	4,355	3,910	3,894	−21	6
		Total, first 30 institutions	$228,189	79%	$208,721	$191,066	$162,977	$146,885	$132,911[b]	9%	11%
31	23	U of Colorado	5,118	86	5,830	6,360	4,134	3,302	3,492	−12	8
32	32	U of Pittsburgh	5,105	79	4,974	4,580	3,965	3,267	2,714	3	13
33	29	Georgia Inst. of Technology	4,889	52	5,260	3,684	3,846	3,401	3,327	−7	8
34	28	U of Utah	4,846	87	5,354	4,840	3,830	3,638	3,364	−9	8
35	35	U of South Carolina	4,622	67	4,432	3,850	3,423	2,721	2,483	4	13
36	31	U of Oregon, main campus	4,462	80	5,087	4,640	4,255	3,351	2,971	−12	8
37	37	Lehigh U	4,410	42	4,237	3,456	3,361	3,664	2,584	4	11
38	43	Virginia Polytechnic Inst. & State U	4,190	55	3,786	3,417	2,686	2,206	1,740	11	19
39	49	U of Virginia	4,169	79	3,436	3,046	2,516	2,069	1,778	21	19
40	54	U of Houston	4,003	44	3,225	2,722	2,117	2,423	1,816	24	17
		Total, first 40 institutions	$274,003	77%	$254,342	$231,661	$197,110	$176,927	$159,180[b]	8%	11%
41	42	Washington State U	3,934	64	3,844	1,356	692	558	583	2	46
42	46	Rutgers U	3,913	65	3,507	2,368	2,301	1,830	1,390	12	23
43	47	U of California, Santa Barbara	3,874	91	3,506	3,060	2,172	1,902	1,698	10	18
44	40	Florida State U	3,841	35	4,047	3,276	3,137	2,500	2,959	−5	5
45	86	U of Cincinnati	3,816	63	1,684	1,593	1,633	1,217	1,251	127	25
46	41	Colorado State U	3,713	88	3,867	2,775	2,688	2,478	2,479	−4	8
47	44	Iowa State U	3,684	43	3,709	2,998	2,239	1,903	1,462	−1	20
48	53	State U of New York, Stony Brook	3,669	73	3,333	3,481	3,084	2,607	2,783	10	6
49	59	U of Washington	3,655	63	2,971	2,964	2,340	2,162	2,276	23	10
50	73	U of Oklahoma	3,633	43	2,301	2,826	2,676	2,890	2,306	58	10
		Total, first 50 institutions	$311,735	75%	$287,111	$258,348	$220,072	$196,974	$178,367[b]	9%	12%
		NATIONAL TOTAL	$507,788	72%	$468,386	$422,087	$369,945	$334,663	$309,371[b]	8%	10%

Note: Data for institutional fiscal years. A number of institutions have developed or are in the process of developing new computer systems and methodologies that enable them to report more accurately the total cost of science and engineering research. Fiscal year 1987 comparisons with data reported in earlier years may be inappropriate in some areas. Data since 1984 were revised in 1987. a Estimated. b Total does not include spending at Rockefeller U. **Source:** National Science Foundation

SCHOOLS WITH MOST FEDERAL SUPPORT FOR CHEMICAL R&D: Big increase at Berkeley

Rank 1987	Rank 1986		1987	1986	1985	1984	1983	1982	Annual change 1986–87	Annual change 1982–87
			($ thousands)							
1	2	U of California, Berkeley	$ 11,160	$ 8,258	$ 9,892	$ 7,263	$ 7,467	$ 5,691	35%	14%
2	1	Massachusetts Inst. of Technology	10,656	12,909	12,424	11,055	8,374	9,096	−17	3
3	3	California Inst. of Technology	9,922	7,612	7,001	5,810	6,554	5,809	30	11
4	5	U of California, Los Angeles	9,414	7,516	6,719	6,389	5,047	4,978	25	14
5	7	Harvard U	8,309	6,748	6,557	6,307	5,224	4,174	23	15
6	4	Stanford U	7,918	7,524	7,097	6,120	5,968	5,893	5	6
7	9	Cornell U	6,753	5,934	6,293	5,775	4,766	5,437	14	4
8	16	Columbia U, main division	6,625	5,030	4,490	4,639	4,279	4,365	32	9
9	6	U of Chicago	6,499	6,769[a]	6,265[a]	5,116	3,998	3,716	−4	12
10	19	U of Texas, Austin	6,405	4,922	4,741	3,873	3,527	2,781	30	18
		Total, first 10 institutions	$ 83,661	$ 73,222	$ 71,479	$ 62,347	$ 55,204	$ 51,940	14%	10%
11	8	U of Illinois, Urbana	6,306	5,999	5,371	5,005	4,668	4,763	5	6
12	11	Purdue U	5,978	5,708	5,418	4,452	3,966	3,946	5	9
13	14	U of Pennsylvania	5,653	5,232	4,398	3,921	4,037	2,745	8	16
14	17	U of Notre Dame	5,158	4,998	5,097	4,416	3,867	3,866	3	6
15	21	Johns Hopkins U	5,116	4,903	4,155	3,783	3,604[a]	3,800	4	6
16	24	Princeton U	5,064	4,575	3,104	2,892	2,642	2,485	11	15
17	25	U of Massachusetts, Amherst	5,036	4,411	4,091	3,887	3,336	2,773	14	13
18	57	Case Western Reserve U	5,016	2,062	2,065	1,904	1,443	1,487	143	28
19	23	Indiana U	4,923	4,757	4,885	4,694	4,642	4,237	3	3
20	15	Pennsylvania State U	4,915	5,161	5,860	4,564	4,236	3,222	−5	9
		Total, first 20 institutions	$136,826	$121,028	$115,923	$101,865	$ 91,549	$ 85,264	13%	10%
21	12	Yale U	4,909	5,566[a]	5,095[a]	3,528	3,008	2,599	−12	14
22	13	U of Wisconsin, Madison	4,718	5,348	5,156	4,391	3,693	3,404	−12	7
23	29	Northwestern U	4,641	3,753	3,963	3,471	3,012	2,711	24	11
24	10	U of California, San Diego	4,599	5,918	4,053	3,780	3,490	3,506	−22	6
25	18	Ohio State U	4,517	4,931	3,846	2,904	2,870	2,355	−8	14
26	20	U of Colorado	4,402	4,911	5,430	3,358	2,695	2,755	−10	10
27	26	U of Minnesota	4,395	4,013	3,295	3,346	3,345	3,377	10	5
28	22	U of Utah	4,194	4,791	4,426	3,380	3,085	2,858	−12	8
29	30	U of Maryland, College Park	4,073	3,557	3,323	2,862	2,834	3,068	15	6
30	27	U of Pittsburgh	4,028	4,045	3,836	3,343	2,833	2,188	0	13
		Total, first 30 institutions	$181,302	$167,861	$158,346	$136,228	$122,510	$114,085	8%	10%
31	36	Texas A&M U	4,019	3,128	4,195	2,735	3,327	2,823	28	7
32	26	U of Oregon, main campus	3,579	4,345	3,959	3,524	2,686	2,530	−18	7
33	37	U of California, Santa Barbara	3,526	3,087	2,709	1,881	1,723	1,480	14	19
34	42	U of Florida	3,486	2,729	2,302	2,042	1,325	1,341	28	21
35	32	U of California, Irvine	3,386	3,394	3,035	2,096	1,725	1,593	0	16
36	41	U of Virginia	3,281	2,748	2,165	2,099	1,663	1,597	19	15
37	34	U of Rochester	3,275	3,336	2,861	3,490	2,800	2,774	−2	3
38	31	Colorado State U	3,273	3,403	2,434	2,426	2,055	2,230	−4	8
39	33	Rockefeller U	3,247	3,377	2,553	833	584	na	−4	—
40	38	U of North Carolina, Chapel Hill	3,153	2,929	2,885	2,699	2,381	2,218	8	7
		Total, first 40 institutions	$215,527	$200,337	$187,444	$160,053	$142,779	$132,671[b]	8%	10%
41	35	U of South Carolina	3,113	3,285	2,787	2,533	2,221	1,865	−5	11
42	40	U of Southern California	2,903	2,857	2,149	2,495	2,456	1,717	2	11
43	51	State U of New York, Stony Brook	2,669	2,210	2,343	2,069	1,809	1,901	21	7
44	46	U of Michigan	2,615	2,367	2,286	2,356	1,853	1,547	10	11
45	39	Georgia Inst. of Technology	2,565	2,914	2,051	2,227	2,032	1,800	−12	7
46	54	Rutgers U	2,525	2,123	2,055	2,129	1,740	1,333	19	14
47	45	Washington State U	2,501	2,414	1,211	682	525	554	4	35
48	47	U of Arizona	2,499	2,291	1,738	1,843	1,557	1,228	9	15
49	81	U of Cincinnati	2,403	1,235	1,022	1,099	748	1,082	95	17
50	58	Brown U	2,363	2,023	1,601	1,579	1,282	1,037	17	18
		Total, first 50 institutions	$241,683	$224,056	$206,687	$179,065	$159,002	$146,735[b]	8%	10%
		NATIONAL TOTAL	$365,480	$338,865	$312,325	$278,215	$247,652	$231,108[b]	8%	10%

Note: Data for institutional fiscal years. A number of institutions have developed or are in the process of developing new computer systems and methodologies that enable them to report more accurately the total cost of science and engineering research. Fiscal 1987 comparisons with data reported in earlier years may be inappropriate in some areas. Data since 1984 were revised in 1987. a Estimated. b Totals do not include Rockefeller U. **Source:** National Science Foundation

SCHOOLS SPENDING MOST ON CHEMICAL ENGINEERING R&D: MIT spends 8% of total

Rank		Chemical engineering			All engineering		
		Total spending ($ thousands)	Federal funds	% federal funds	Total spending ($ thousands)	Federal funds	% federal funds
1	Massachusetts Inst. of Technology	$ 11,147	$ 7,333	66%	$ 110,835	$ 80,331	72%
2	U of Minnesota	6,283	3,614	58	23,161	8,280	36
3	U of Texas, Austin	4,291	1,728	40	44,682	21,489	48
4	New Mexico Inst. of Mining & Tech.	4,127	407	10	20,335	7,451	37
5	John Hopkins U	3,571[a]	3,550[a]	99	172,790	170,869	99
6	U of Wisconsin, Madison	3,518	2,123	60	30,076	18,810	63
7	North Carolina State U, Raleigh	3,348	1,044	31	24,068	8,132	34
8	U of Maryland, College Park	3,280	1,037	32	34,532	15,881	46
9	Brigham Young U	3,277	2,067	63	5,242	3,151	60
10	Texas A&M U	2,909	234	8	33,385	8,467	25
	Total, first 10 institutions	$ 45,751	$23,137	51%	$ 499,106	$ 342,861	69%
11	Stanford U	2,907	2,605	90	68,008	56,610	83
12	Lehigh U	2,508	821	33	16,995	5,866	35
13	U of Delaware	2,304	987	43	11,699	4,954	42
14	U of Pennsylvania	2,194	1,655	75	8,745	4,808	55
15	Georgia Inst. of Technology	2,162	1,134	52	84,329	44,239	52
16	U of Michigan	2,131	1,532	72	35,850	18,566	52
17	Columbia U, main division	2,122	227	11	12,806	9,743	76
18	Case Western Reserve U	2,115	1,495	71	14,104	10,072	71
19	Louisiana State U	1,920	694	36	8,480	2,129	25
20	U of Washington	1,919	1,022	53	19,101	10,453	55
	Total, first 20 institutions	$ 68,033	$35,309	52%	$ 779,223	$ 510,301	65%
21	Pennsylvania State U	1,907	687	36	68,326	45,736	67
22	Cornell U	1,886	1,064	56	35,128	21,592	61
23	Princeton U	1,801	959	53	15,084	9,873	65
24	California Inst. of Technology	1,776	1,525	86	14,436	12,357	86
25	Purdue U	1,735	1,104	64	30,371	19,104	63
26	U of California, Berkeley	1,719	1,185	69	39,888	24,446	61
27	U of Pittsburgh	1,682	1,172	70	5,908	3,185	54
28	U of Houston	1,556	578	37	7,359	2,609	35
29	Auburn U	1,493	542	36	15,290	7,166	47
30	Syracuse U	1,473	648	44	4,985	2,147	43
	Total, first 30 institutions	$ 85,061	$44,773	53%	$1,015,998	$ 658,516	65%
	NATIONAL TOTAL	$140,438	$69,880	50%	$1,888,718	$1,111,740	59%

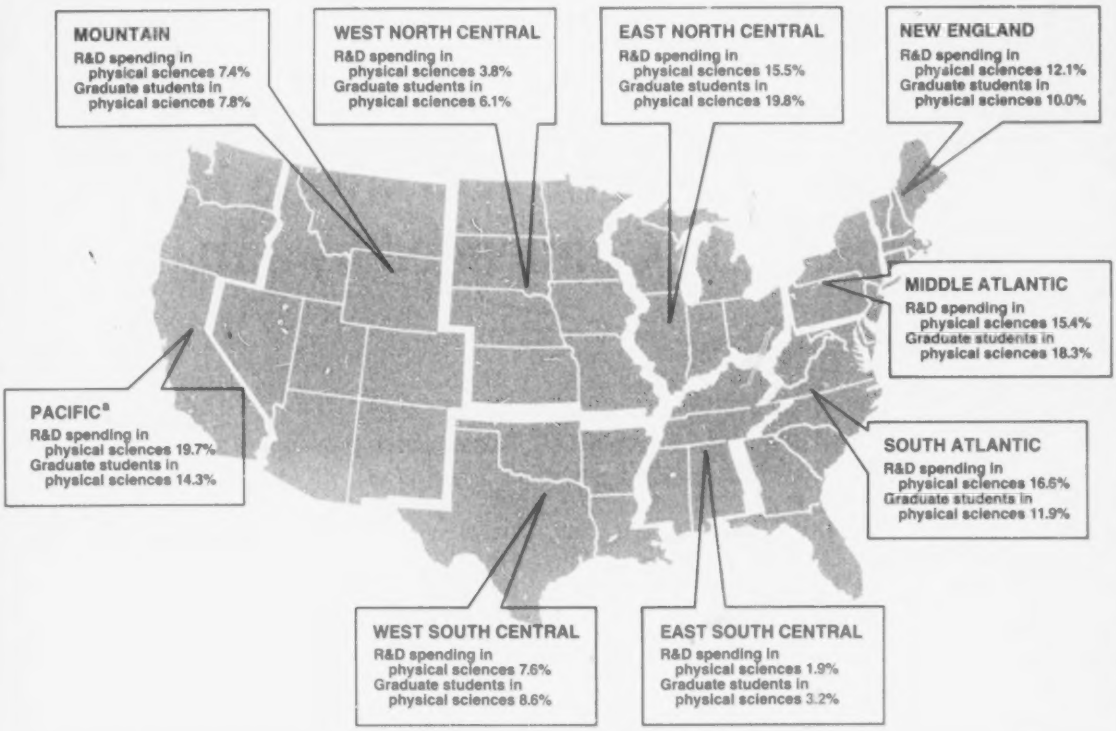
Note: Data for fiscal 1987. a Estimated. **Source:** National Science Foundation

FOREIGN GRADUATE STUDENTS: Their fraction of total is growing in all fields

	1987		1986		1985		1984		1983		1982		Annual change	
	Thousands	% of total	Thousands	% of total	Thousands	% of total	Thousands	% of total	Thousands	% of total	Thousands	% of total	1986–87	1982–87
All sciences	**48.8**	**24%**	**46.3**	**23%**	**42.5**	**22%**	**38.6**	**20%**	**37.5**	**20%**	**34.5**	**18%**	**5%**	**7%**
Psychology and social sciences	13.2	18	12.7	18	12.1	18	11.2	18	11.2	16	10.8	15	4	4
Life sciences	13.2	19	12.2	18	11.0	17	10.2	15	10.0	15	9.3	14	9	7
Biochemistry	1.2	26	1.1	23	1.0	22	0.8	20	0.8	19	0.7	17	9	13
Mathematical and computer sciences	10.9	42	10.4	41	9.5	41	8.3	40	7.6	39	6.5	36	5	11
Physical sciences	9.6	35	9.3	34	8.3	32	7.4	30	7.0	29	6.3	27	4	9
Chemistry	4.7	30	4.4	28	4.0	26	3.5	24	3.4	23	3.1	22	8	9
Physics	4.7	43	4.7	44	4.1	41	3.8	38	3.5	38	3.1	35	0	9
Environmental sciences	1.9	18	1.8	16	1.6	15	1.6	14	1.7	14	1.6	15	4	3
Engineering	**27.3**	**45**	**26.6**	**44**	**23.7**	**43**	**22.8**	**42**	**22.4**	**42**	**20.8**	**43**	**3**	**6**
Chemical	2.3	41	2.2	39	2.2	40	2.1	37	2.2	38	2.3	42	7	0
Metallurgical and materials	1.5	45	1.5	45	1.3	42	1.2	42	1.2	43	1.2	48	3	5
TOTAL	**76.2**	**29%**	**73.0**	**28**	**66.2**	**26**	**61.4**	**25**	**59.9**	**25**	**55.3**	**23**	**4%**	**7%**
ANNUAL CHANGE	**4.4%**		**10.2%**		**7.7%**		**2.5%**		**8.4%**		**5.1%**			

Note: Data are for full-time graduate students at Ph.D.-granting institutions only. **Source:** National Science Foundation

Three fifths of R&D funding and graduate students are east of Mississippi River


MOUNTAIN
R&D spending in physical sciences 7.4%
Graduate students in physical sciences 7.8%
WEST NORTH CENTRAL
R&D spending in physical sciences 3.8%
Graduate students in physical sciences 6.1%
EAST NORTH CENTRAL
R&D spending in physical sciences 15.5%
Graduate students in physical sciences 19.8%
NEW ENGLAND
R&D spending in physical sciences 12.1%
Graduate students in physical sciences 10.0%
MIDDLE ATLANTIC
R&D spending in physical sciences 15.4%
Graduate students in physical sciences 18.3%
PACIFIC[a]
R&D spending in physical sciences 19.7%
Graduate students in physical sciences 14.3%
SOUTH ATLANTIC
R&D spending in physical sciences 16.6%
Graduate students in physical sciences 11.9%
WEST SOUTH CENTRAL
R&D spending in physical sciences 7.6%
Graduate students in physical sciences 8.6%
EAST SOUTH CENTRAL
R&D spending in physical sciences 1.9%
Graduate students in physical sciences 3.2%

Key to map: Using the Middle Atlantic states as an example, 15.4% of all R&D expenditures in the physical sciences and 18.3% of all graduate students in the physical sciences at Ph.D.-granting universities and colleges are in this area.

Note: Data based on $1.35 million of R&D expenditures and 31,000 graduate students enrolled in the physical sciences at Ph.D.-granting colleges and universities during the 1987 fiscal year. a Includes Alaska, Hawaii, and outlying areas. **Source:** National Science Foundation

GRADUATE SCIENCE STUDENTS: Little change in 1987 for either science or engineering

Thousands	1987	1986	1985	1984	1983	1982	1981	1980	1979	1978	1977	Annual change 1986–87	Annual change 1977–87
All sciences	290.7	286.5	280.6	274.8	271.8	268.6	265.6	263.5	253.4	245.5	242.2	1%	2%
Psychology and social sciences	108.1	105.3	104.6	104.2	105.5	107.3	108.7	109.7	105.8	101.2	100.6	3	1
Life sciences	96.6	95.8	93.3	92.4	91.2	90.7	90.9	90.7	87.5	85.9	83.3	1	1
Biochemistry	4.8	4.9	4.7	4.5	4.2	4.1	4.0	4.0	3.9	4.0	3.8	−2	2
Mathematical and computer sciences	41.6	40.9	39.1	35.4	33.2	30.3	27.1	25.0	22.7	21.5	21.1	2	7
Physical sciences	31.0	30.5	29.3	28.4	27.7	26.5	25.8	25.4	24.9	24.7	24.8	1	2
Chemistry	17.6	17.6	17.2	16.6	16.5	15.8	15.2	15.1	14.9	14.8	14.6	0	2
Physics	12.3	12.0	11.3	11.0	10.5	10.0	9.9	9.6	9.3	9.2	9.5	3	3
Environmental sciences	13.5	14.1	14.3	14.3	14.3	13.8	13.1	12.8	12.6	12.2	12.3	−4	1
Engineering	98.0	96.9	91.4	88.3	86.4	78.2	74.4	70.1	67.2	64.3	64.4	1	4
Chemical	7.0	6.9	7.0	7.2	7.4	6.9	6.3	5.9	5.4	5.2	5.1	2	3
Metallurgical and materials	4.2	4.0	3.8	3.6	3.3	3.0	3.0	2.8	2.7	2.5	2.5	3	5
Petroleum	0.8	0.7	0.8	0.7	0.7	0.6	0.5	0.5	0.4	0.4	0.4	13	7
TOTAL	388.7	383.5	372.0	363.1	358.3	346.8	340.0	333.7	320.6	309.8	306.6	1	2
ANNUAL CHANGE	1%	3%	2%	1%	3%	2%	2%	4%	3%	1%	3%		

Note: Data for Ph.D.-granting institutions only. **Source:** National Science Foundation

U.S. Dominance of Worldwide R&D Increasingly Challenged by Japan

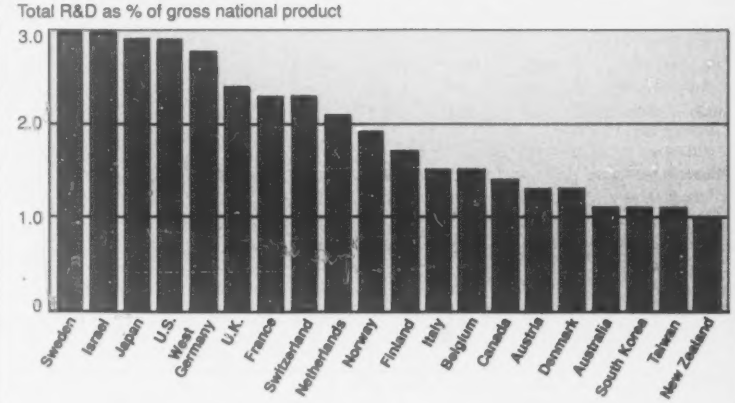
WORLDWIDE R&D SCIENTISTS AND ENGINEERS: Researchers growing as share of work force

Thousands	1987	1986	1985	1984	1983	1982	1981	1980	1979	1978	1977	Annual change 1986–87	Annual change 1977–87
U.S.	806	791	773	746	723	703	683	651	615	587	561	2%	4%
Japan	418	406	381	370	342	330	318	303	282	273	272	3	4
West Germany	152[a]	147[a]	144	137[a]	131	128[a]	125	121[a]	117	113[a]	111	3	3
France	108[a]	105[a]	102	98	93	90	86	75	73	71	68	3	5
U.K.	na	99	98	96[a]	94	na	96	na	na	88	na	1[b]	—
Per 10,000 in labor force													
U.S.	na	66.2	65.9	64.7	63.8	62.8	61.9	60.0	57.7	56.5	55.7	—	—
Japan	na	67.4	63.9	62.4	58.1	57.1	55.6	53.6	50.4	49.4	49.9	—	—
West Germany	na	52.3[a]	51.6	49.6[a]	47.4	46.4[a]	45.5	44.3[a]	43.4	42.7[a]	41.8	—	—
France	na	43.8[a]	42.8	41.1	39.1	37.9	36.3	32.1	31.4	30.7	29.7	—	—
U.K.	na	35.5	35.5	35.5[a]	35.4	na	35.8	na	na	33.3	na	—	—

Note: Table represents all scientists and engineers engaged in R&D on a full-time equivalent basis except Japan, whose data include persons primarily employed in R&D in the natural sciences and engineering, and all higher education natural science and engineering faculty. The U.K. data include only the government and industry sectors. The figures for West Germany increased in 1979 partially because of increased coverage of small and medium-sized enterprises not surveyed in 1977. The data for France increased in 1981 in part due to a reevaluation of university research efforts. **na** = not available. **a** Estimated. **b** Annual change is for 1985–86. **Source:** National Science Foundation

Sweden, Israel spend biggest part of GNP on R&D

Total R&D as % of gross national product



Note: Data are for most current year available. **a** C&EN estimate based on NSF data.
Source: National Science Foundation

WORLDWIDE R&D EXPENDITURES: 20 countries spend more than $1 billion on R&D annually

$ Millions, constant 1982		% of GNP	$ Millions, constant 1982		% of GNP	$ Millions, constant 1982		% of GNP
U.S. (1987)	$110,100	2.9%	**Netherlands** (1985)	3,100	2.1	**South Korea** (1983)	1308	1.1
Japan (1987)	39,118	2.9	**Switzerland** (1983)	2,131	2.3	**Finland** (1987)	1236	1.7
West Germany (1987)	19,371	2.8	**Spain** (1984)	1,762	0.5	**Argentina** (1981)	1087	0.4
U.K. (1986)	13,765	2.4	**Australia** (1985)	1,718	1.1	**Norway** (1987)	1007	1.9
France (1987)	13,728	2.3	**India** (1984)	$1482	0.9%	**Denmark** (1985)	707	1.3
Italy (1987)	7,394	1.5	**Brazil** (1985)	1448	0.7	**Israel** (1983)	637	3.0
Canada (1986)	4,877	1.4	**Belgium** (1983)	1442	1.5	**Taiwan** (1985)	505	1.1
Sweden (1987)	3,967	3.0	**Austria** (1987)	1310	1.3	**New Zealand** (1985)	204	1.0

Note: Data are for the most current year available (in parentheses). Countries differ in statistical collection capabilities and definitions. In addition, some R&D/gross national product percentages are R&D/gross domestic product. Foreign currency conversions to U.S. dollars were calculated with Organization for Economic Cooperation & Development purchasing power parities or using International Monetary Fund average-for-period par/market exchange rates. **Source:** National Science Foundation

TOTAL AND NONDEFENSE R&D: U.S. lead shrinks when only nondefense R&D is considered

												Annual change	
$ Billions, constant 1982	**1987**	**1986**	**1985**	**1984**	**1983**	**1982**	**1981**	**1980**	**1979**	**1978**	**1977**	**1986–87**	**1977–87**
TOTAL R&D													
U.S.[a]	$110.1	$106.9	$103.8	$95.1	$86.2	$80.4	$76.5	$73.0	$69.9	$66.7	$63.6	2%	5%
Japan	39.1	36.6	36.1	32.4	29.9	27.4	25.5	23.1	21.0	19.1	18.0	7	8
West Germany	19.4	18.6	18.5	16.9	16.4	16.3	15.9	15.3	15.0	13.3	12.4	4	5
U.K.	na	13.8	12.9	na	11.9	na	12.2	na	na	11.1	na	7[b]	—
France	13.7	13.6	13.1	12.6	11.9	11.5	10.8	9.8	9.4	8.9	8.6	1	5
NONDEFENSE R&D													
U.S.[a]	$ 72.7	$ 71.6	$ 70.6	$66.6	$62.1	$59.5	$58.1	$56.9	$53.8	$50.0	$47.0	1%	4%
Japan	38.8	36.3	35.8	32.2	29.7	27.2	25.4	23.0	20.8	18.9	17.9	7	8
West Germany	18.4	17.7	17.6	16.2	15.7	15.6	15.2	14.5	14.2	12.5	11.6	4	5
U.K.	na	10.3	9.2	na	8.4	na	8.7	na	na	8.0	na	12[b]	—
France	10.9	10.9	10.5	9.9	9.4	9.0	8.1	7.6	7.4	7.1	7.0	0	5

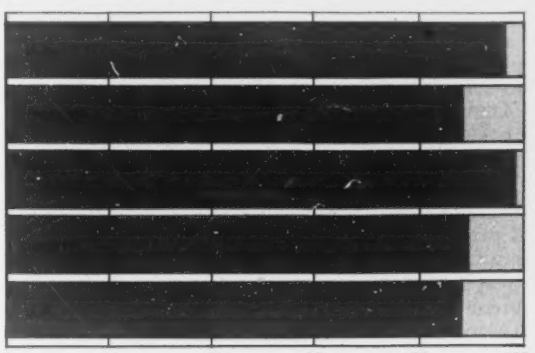
Note: Foreign currency conversions to U.S. dollars are calculated based on Organization for Economic Cooperation & Development purchasing power parity exchange rates. a C&EN estimates based on NSF data. b Annual change is for 1985–86. **na** = not available. **Source:** National Science Foundation

ORIGIN OF CHEMICAL LITERATURE: Japan's share rises as Soviet Union's declines

% of total[a]	1988	1984	1980	1976	1972
U.S.	27.4%	27.1%	26.2%	25.6%	28.0%
U.S.S.R.	13.0	16.8	19.0	24.1	24.0
Japan	11.5	10.4	10.4	7.8	7.9
West Germany	6.3	6.0	5.8	5.9	5.7
U.K.	5.6	5.6	5.9	6.4	6.4
France	4.3	4.0	4.2	4.2	4.4
China	3.5	2.3	0.7	0.1	0.0
Canada	3.1	2.8	2.6	2.7	2.8
India	3.1	3.2	3.4	2.8	2.5
Italy	2.4	2.5	2.4	2.0	1.9
Poland	1.7	1.7	2.1	2.0	2.0
Netherlands	1.5	1.4	1.2	1.1	1.0
Spain	1.4	1.0	0.7	0.5	0.4
Australia	1.3	1.3	1.2	1.2	1.2
East Germany	1.2	1.2	1.2	1.2	0.5
Sweden	1.2	1.2	1.1	1.1	1.1
Czechoslovakia	1.1	1.2	1.4	1.5	1.7
Switzerland	1.1	1.0	1.0	1.1	1.0
All others	9.3	9.3	9.5	8.7	7.5
TOTAL PAPERS (THOUSANDS)	389.7	380.7	407.3	318.0	280.1

a Source of journal literature abstracted in *Chemical Abstracts* based on authors address. **Source:** Chemical Abstracts Service

Industry's share of R&D outlays is greatest in Japan



a Estimated. b Data are for 1987. **Source:** National Science Foundation

ACS-PRF Grants Approved

Acting on recommendations from the May meeting of the Petroleum Research Fund Advisory Board, the ACS Board of Directors approved 155 new or continuing ACS-PRF grants totaling $4,106,471. The recommended grants were selected from 467 proposals and are the last projects to be funded in 1989. Total ACS-PRF grant commitments in 1989 total $12,683,447. ACS-PRF grants are funded by income from a trust established in 1944 by seven major oil companies. No ACS member dues income is used for PRF grants or administrative expenses.

The PRF Advisory Board has begun a review of the adequacy and appropriateness of current PRF grant programs. Scientists wishing to comment on any aspect of PRF operations, or to suggest possible new grant programs, are invited to communicate with the program administrator, Joseph E. Rogers Jr., at the address below.

Proposals for projects to commence in 1990 are invited for all ACS-PRF research grant programs. Information and application forms may be obtained from the Petroleum Research Fund, American Chemical Society, 1155—16th St., N.W., Washington, D.C. 20036, or by calling (202) 872-4481.

ACS-PRF Grants for Fundamental Research in the Petroleum Field (Type AC)

Brent Koplitz, Tulane U. Laser-Induced Photochemistry of Metalorganic Compounds Relevant to the Fabrication of III-IV Semiconductor Materials. $40,000

Frederick G. Bordwell, Northwestern U. Structural Effects on Homolytic Bond Dissociation Energies of Weak Acids. $40,000

Bruce H. Lipshutz, U of California, Santa Barbara. Development and Applications of Novel Organocopper-Mediated Transmetalation Processes. $40,000

Ryong-Joon Roe, U of Cincinnati. Solubility of Homopolymer in Block Copolymer. $40,000

Jeffrey L. Petersen, West Virginia U. Systematic Reactivity Studies of Highly Electrophilic Sila-Metallacyclobutane and Cationic Metallocene Alkyl Complexes. $40,000

M. David Curtis, U of Michigan. Chemistry of Monocyclopentadienyl Complexes of Niobium and Tantalum. $40,000

Cheng-cher Huang, U of Minnesota. Physical Properties of Chiral Liquid Crystal Compounds. $40,000

James M. Lisy, U of Illinois, Urbana-Champaign. Vibrational Spectroscopy of Metal Ion-Solvent Clusters. $40,000

Timothy P. Lodge, U of Minnesota. Diffusion of Linear and Star Polymers in Random Media. $40,000

John E. Ellis, U of Minnesota. Studies on the Hexacarbonylmetallates(2-) of Titanium, Zirconium, and Hafnium and Related Materials. $20,000

Darrel S. Cowan, U of Washington. Structural Evolution and Kinematic History of the Badwater Turtleneck Detachment Fault, Death Valley, California. $40,000

Emanuel Mazor, Weizmann Institute of Science. ^4He and ^{40}Ar Dating of Natural Gas and Oil. $20,000

T. Darrah Thomas, Oregon State U. Electron Spectroscopic and Theoretical Investigations of Small Molecules. $40,000

Richard C. Larock, Iowa State U. Organic Synthesis via Palladium Migration. $40,000

Elizabeth L. Miller, Stanford U. Paleozoic and Mesozoic Geology and Geochronology of the Pine Forest Range, Northwest Nevada. $39,523

Jayanth R. Banavar, Pennsylvania State U. Diffusion in Porous Media. $40,000

Herbert F. Wang, U of Wisconsin, Madison. Flexural and Thermal Modeling of the Midcontinent Rift. $40,000

Michael W. W. Adams, U of Georgia. The Metabolism of Gases by Extremely Thermophilic Bacteria. $40,000

William D. Johns, U of Missouri, Columbia. Experimental High-Temperature-Pressure Compaction Diagenesis of Shale. $40,000

Rudiger Dieckmann, Cornell U. Problems in the Application of Electrochemical Devices for Coulometric Titrations with Doped Zirconia as Electrolyte. $40,000

George W. Luther III, U of Delaware. Investigation of the Reactivity of Pyrite with Inorganic and Organic Compounds. $40,000

Martyn Poliakoff, U of Nottingham. Time-Resolved Infrared Studies in Supercritical Xenon. $40,000

Jeffrey L. Bada, U of California, San Diego. Organic Geochemical Applications of Two-Step Laser Mass Spectrometry. $40,000

Thomas G. Richmond, U of Utah. Carbon-Heteroatom Bond Activation. $40,000

Gautam Mitra, U of Rochester. Tectonothermal Evolution of the Southern Anthracite Region, Pennsylvania: Implications for the Development of Blind Thrust Systems. $39,950

Stephen L. Buchwald, Massachusetts Institute of Technology. Early Transition-Metal Complexes of Multiply Unsaturated Organic Molecules. $40,000

Robert W. Murray, U of Missouri, St. Louis. Dioxirane Chemistry. $40,000

Stephen J. Guggenheim, U of Illinois, Chicago. The Thermal Stability of Trioctahedral Layer Silicates. $40,000

Bernard D. Coleman, Rutgers U. Rheology of Cold Drawing of Polymeric Materials. $40,000

Carlton E. Brett, U of Rochester. Dynamic Stratigraphy of the Wenlockian Series (Upper Silurian) in the Northern Appalachian Basin. $40,000

Frank A. Podosek, Washington U. Study of Natural Isotopic Fractionation Effects in Iron. $40,000

Dennis P. Curran, U of Pittsburgh. Sequential Carbon-Carbon Bond Formation: the Combination of Radical and Ionic Reactions. $40,000

John C. Wright, U of Wisconsin, Madison. Geochemical Applications of Site-Selective Laser Spectroscopy. $40,000

William Weltner Jr., U of Florida. ESR, ENDOR, and Far-IR Spectroscopy of Clusters. $40,000

Jacqueline Krim, Northeastern U. Investigation of Self-Affine Surface Fractals through Adsorption Isotherms. $40,000

Mark O. Robbins, Johns Hopkins U. Dynamics of Fluid Interfaces in Porous Media: Viscous Fingering and the Depinning Transition. $40,000

Harry M. Walborsky, Florida State U. Stereochemistry of Capto-Dative Reactions. $40,000

John F. Garst, U of Georgia. Mechanism of the Barbier Synthesis. $40,000

George A. McMechan, U of Texas, Dallas. Numerical Simulation of the Elastic Seismic Response of Hydrocarbon Reservoirs Using Biot Theory. $40,000

Stephen Garoff, Carnegie Mellon U. Origins of Dynamic Wettability and Contact Angle Hysteresis. $40,000

Jeremy N. S. Evans, Washington State U. Rapid Reactions by Solid-State NMR. $40,000

Jorge V. Jose, Northeastern U. Theoretical Studies of Nonlinear and Dynamic Effects in Disordered Media. $40,000

R. Paul Philp, U of Oklahoma. The Use of Tandem Mass Spectrometry (MS/MS) in the Search for Novel High-Molecular-Weight Biomarkers. $40,000

Glen A. Russell, Iowa State U. Chain Reactions Involving Electron Transfer. $40,000

Thomas Bein, U of New Mexico. Encapsulation of Heterobimetallic Species in Large-Pore Zeolites. $40,000

Anthony J. McHugh, U of Illinois, Urbana-Champaign. Flow-Induced Structure Formation and Phase Separation in Polymer Solutions. $38,250

Thomas F. Keyes, Boston U. Normal Mode Analysis of Liquid State Dynamics. $40,000

Richard D. Ernst, U of Utah. Synthesis, Characterization, and Reaction Chemistry of Transition-Metal Polyhydride Compounds. $40,000

Tadeusz W. Zerda, Texas Christian U. Hydrolysis Reaction in Sol-Gel Processes. $40,000

Kirk S. Schanze, U of Florida. Ligand-to-Ligand Charge Transfer States of Re(I) Complexes. $40,000

William C. Kelly, U of Michigan. Geologic and Thermochemical History of the White Pine District, Keweenaw Rift, Northern Michigan. $40,000

John R. Bowman, U of Utah. Stable Isotope and Hydrothermal Alteration Studies of Fluid Rock Interaction in Basin and Range Normal Faults. $40,000

Arun Bansil, Northeastern U. Electronic Structure of Some Model Bimetallic Transition-Metal Catalysts. $40,000

Joseph W. Kolis, John D. Petersen, Clemson U. Preparation of New Metallated Conducting Polymers. $40,000

Eric W. Kaler, U of Washington. Properties of the L3 Surfactant Phase. $40,000

Kenneth M. Nicholas, U of Oklahoma. Stereoselective Reactions of Polynuclear Propargylium Complexes. $40,000

Claude Cohen, Cornell U. Conformation of Chains in Swollen Networks. $40,000

Shelton Bank, State U of New York, Albany. Reactions of Imine Intermediates on Clay Catalysts as Characterized by Solid-State NMR Spectroscopy. $40,000

Don Secrest, U of Illinois, Urbana-Champaign. Angular Momentum in Molecular Collisions. $40,000

David F. O'Brien, U of Arizona. Supramolecular Assemblies of Polydiacetylenes and Polyacetylenes. $40,000

James C. Weisshaar, U of Wisconsin, Madison. Time-Dependent Decay of Gas-Phase Transition-Metal Cluster-Adsorbate Complexes. $40,000

J. Dungan Smith, U of Washington. Reconstruction of Ancient Sandy-Fluvial Environments Using Recently Developed Environmental Fluid Mechanical and Sediment Transport Techniques. $40,000

Peter E. Siska, U of Pittsburgh. Relationship between Orbital Structure and Nonbonded Interactions Studied in Penning Ionization Electron Spectroscopy (PIES). $40,000

M. Stanley Whittingham, State U of New York, Binghamton. Reactivity and Transport Properties of Single-Crystal Aluminosilicates. $40,000

Eldred H. Chimowitz, U of Rochester. The Resolution and Separation of Molecules with Near-Critical Fluids. $40,000

Jay B. Benziger, Princeton U. Reactivity of Benzene Derivatives on Metal Surfaces. $40,000

Bruce E. Bursten, Ohio State U. Photochemical Alkyne Activation by Dinuclear Organometallic Complexes. $40,000

Stig M. Bergstrom, Ohio State U. Geologic Evolution of the Ordovician Sebree Trough, a Major Subsurface Feature in the North American Midcontinent Region. $30,338

David M. Coleman, Wayne State U. Spectroscopic and Analytical Studies of a Dual Inductively Plasma Discharge. $40,000

Franklin A. Schultz, Indiana U-Purdue U, Fort Wayne. Electrocatalytic Properties of Oxo Metal Complexes in Special Chemical Environments. $40,000

Joseph P. Dinnocenzo, U of Rochester. Cation Radical Rearrangements. $40,000

Charles M. Lukehart, Vanderbilt U. Photochemical Reactivity of Dinuclear Compounds Containing μ-Alkenylidene Ligands. $40,000

ACS-PRF Grants for Fundamental Research in the Petroleum Field (Type B)

Ronald Caple, U of Minnesota, Duluth. Utilization of I(III) Reagents To Create Carbon-Carbon Bonds. $20,000

Kenneth L. Stevenson, Indiana U-Purdue U, Fort Wayne. The Photochemistry of Copper(I) Complexes in Solution. $20,000

Christopher P. Dewey, Mississippi State U. Ostracode Micropaleontology of the Mississippi Strata of the Black Warrior Basin. $20,000

Paul Siders, U of Minnesota, Duluth. Theory of Electron Transfer in an Orientationally Ordered Monolayer. $20,000

Wayne R. Tikkanen, California State U, Los Angeles. Functionalized Group-4 Metalocenes as Ligands for Binuclear Complexes of Early and Late Transition Metals. $20,000

Timothy D. Lash, Illinois State U. New Syntheses of Porphyrins and Porphyrin Dimers with Exocyclic Rings. $20,000

Kerry K. Karukstis, Harvey Mudd C. Studies of Substituted Coumarins and Pyrones as Photosynthetic Electron Transport Inhibitors. $20,000

Alan M. Rosan, Drew U. Organo-Manganese Chemistry: Allyl and Olefin Complexes of η5-Cyclopentadienyl Manganese Dicarbonyl. $20,000

Daniel P. Gerrity, Reed C. Resonance Raman Studies of Group VIB Metal Hexacarbonyls. $20,000

Eric L. Hardegree, Abilene Christian U. The Effect of Sulfur or Carbon Overlayers on the Adsorption of Small Alkenes and Alcohols by Molybdenum Surfaces. $20,000

Franklin P. DeHaan, Occidental C. Kinetics and Mechanisms of Electrophilic Aromatic Nitration and Acylation-Related Reactions. $20,000

Patricia B. O'Hara, Amherst C. Energy Transfer as a Probe of Bimolecular Dynamics. $20,000

Hamid S. Kasmai, East Tennessee State U. Synthesis of New π-Donors and π-Acceptors for Organic Metals. $20,000

Abul Hussam, George Mason U. A Precise Study of Solubilization in Ultralow Interfacial Tension Microemulsions. $15,000

David T. King Jr., Auburn U. Nature and Origin of Marl-Limestone Sequences Comprising the Upper Cretaceous Arcola Limestone, Central and Eastern Alabama. $19,995

John T. Shaw, Grove City C. Annulation Reactions of 1,3,6,9b-Tetraazaphenalene and Related Compounds. $20,000

Merlyn D. Schuh, Davidson C. Collision-Induced Redistribution of Vibrational Energy in 2,3-Diazabicyclo[2.2.1]hept-2-ene and Propynal. $20,000

Thomas J. Smith, Kalamazoo C. Electron Transfer Studies on Polynuclear Transition-Metal Complexes. $20,000

Mark E. McGuire, Eastern Illinois U. Synthesis, Characterization, and Charge Transfer Properties of Tri- and Tetrametallic (Ru and Os) Complexes. $20,000

Christopher J. Abelt, C of William & Mary. Insertion Reactions of Cyclodextrin-Bound Carbenes. $20,000

Rick C. White, Sam Houston State U. Photochemistry of Cyclic Carbonate Esters. $20,000

John N. Cooper, Bucknell U. The Cobalt(II)-Catalyzed Substitution of Sulfite on Halobis(Ethylenediamine) Cobalt(III) Complexes. $20,000

ACS-PRF Grants for Fundamental Research in the Petroleum Field (Type G)

Alec M. Wodtke, U of California, Santa Barbara. Controlling Chemical Reactions Using Lasers. $18,000

William S. Hammack, Carnegie Mellon U. High-Pressure Vibrational Spectroscopy of Cation-Site Interactions in Magnesium-Sodium-Borate Glasses. $18,000

Joseph B. Schlenoff, Florida State U. Electrochemical Synthesis and Properties of Conducting Polymers Grown in Liquid Crystals. $18,000

Dean M. Giolando, U of Toledo. General Routes of Alkeneditellurides: Exploring the Synthetic Utility of Tin-Telluride Compounds. $18,000

Nancy W. Hinman, U of Montana. Relative Effects of Organic and Inorganic Constituents on Rates of Silica Diagenesis in the Monterey Formation, California. $18,000

I. Jonathan Amster, U of Georgia. Gas-Phase Reactions of Laser-Desorbed Peptide Molecules with Transition-Metal Ions. $18,000

Paul A. Lindahl, Texas A&M U. Electrocatalytic Studies of Carbon Monoxide Dehydrogenase. $18,000

Lawrence S. Brown, Texas A&M U. Experimental Investigation of Infrared Laser-Induced Desorption and Energy Transfer at the Gas-Solid Interface. $18,000

Silas C. Blackstock, Vanderbilt U. Condensed-Phase Study of Some Distonic Radical Cations. $18,000

Alon McCormick, U of Minnesota. NMR Investigation of Zeolite Synthesis. $18,000

Thomas C. Halsey, U of Chicago. Structure and Dynamics of Electrorheological Fluids. $18,000

Leonard E. Klebanoff, Lehigh U. Interface Magnetism and Structure. $18,000

Cynthia K. Schauer, U of North Carolina, Chapel Hill. Heteroatom-Substituted Metal Carbonyl Clusters as Molecular Building Blocks to New Solid-State Materials. $18,000

Christopher J. Flann, U of Montana. Asymmetric Synthesis via *N*-Phosphinyl Imines. $18,000

Elizabeth A. Burton, Northern Illinois U. Experimental Investigation of the Effect of Fluid Chemistry on Crystal Morphologies of Calcium Carbonate Cements. $18,000

George H. Watson, U of Delaware. Classical Wave Localization and Propagation in Disordered Structures. $18,000

Steven W. Buckner, U of Arizona. Kinetic Energy Release Studies in Fourier Transform Ion Cyclotron Resonance Spectroscopy. $18,000

Adrian Goldman, Rutgers U. Understanding Lignin Breakdown: the Structure of Ligninase. $18,000

Srinivas Sridhar, Northeastern U. Dielectric Spectroscopy from KHz to 75 GHz in Polymers and Microemulsions. $18,000

Alan J. Russell, U of Pittsburgh. Designing Enzymes for Use in Anhydrous Hydrophilic Organic Solvents. $18,000

Karen B. Sentell, U of Vermont. Subambient Temperature as a Separation Parameter for Reversed-Phase Liquid Chromatography. $18,000

Phillip M. Duxbury, Michigan State U. Theoretical Studies of Breakdown in Random Media. $18,000

Werner G. Kuhr, U of California, Riverside. Optimization of Indirect Electrochemical Detection for Capillary Zone Electrophoresis. $18,000

Mark T. Brandon, Yale U. Finite Strain in Deformed Sediments from an Active Accretionary Wedge. $18,000

Mark E. Thompson, Princeton U. Solid-State Membranes. $18,000

Howard A. Stone, Harvard U. Deformation and Interaction of Two Droplets with Application to Droplet Coalescence. $18,000

Edward J. Brush, Tufts U. Mechanisms of Enzymatic Nitrile Degradation. $18,000

Alice E. Bruce, U of Maine, Orono. Low-Valent Transition-Metal Imido Complexes. $18,000

Eric N. Jacobsen, U of Illinois, Urbana-Champaign. Design and Study of Coordination Compounds That Catalyze Asymmetric Organic Reactions. $18,000

Alfred T. D'Agostino, U of South Florida. Using X-Ray Photoelectron Spectroscopy To Determine the Outer Potential of Emersed Electrodes. $18,000

James V. Coe, Ohio State U. Cluster Ion Source Development for High-Resolution Infrared Spectroscopy. $18,000

Richey M. Davis, Virginia Polytechnic Institute and State U. Quasielastic Light Scattering of Semidilute Polyelectrolyte Solutions. $18,000

Viresh H. Rawal, Ohio State U. Chemistry of Strained Ring Compounds. $18,000

Robert J. Lad, U of Maine, Orono. High-Temperature Reactivity of Nonstoichiometric Carbide and Nitride Surfaces. $18,000

Gary F. Holland, U of Utah. Electrochemical Modification of Mixed-Conducting, Nonstoichiometric Metal Oxides. $18,000

Peyman Givi, State U of New York, Buffalo. Mixing and Reaction in Turbulent Flows. $18,000

Lisa E. Osterman, George Washington U. Benthic Foraminiferal Record of the Eastern Arctic Basin. $18,000

Benny E. Arney Jr., Sam Houston State U. Preparation and Development of Synthetically Useful Cyclopropenes and Cyclopropene Synthons. $18,000

JoAnn P. DeLuca, Illinois State U. Effect of Solvents and Nucleophilic Directing Groups on the Reactions of Singlet Carbenes. $18,000

Robert C. Scarrow, Haverford College. Structure and Reactivity of the Nonheme Iron Center in Lipoxygenase. $18,000

Donald R. Schreiber, Western Michigan U. Thermodynamic Properties of Transition Metals in Aqueous Electrolyte Solutions. $18,000

Mark S. Drummond, U of Alabama, Birmingham. Igneous Petrogenesis and Tectonic Setting of the Elkahatchee Quartz Diorite, Alabama Appalachians: Implications for Cambro-Ordovician Magmatism in the Eastern Blue Ridge. $18,000

Joanne L. Stewart, Hope C. Synthesis of Molecular Precursors to Electronic Ceramics. $18,000

Elizabeth A. Stemmler, Bowdoin C. Catalytic Oxidation Reactions for the Detection and Differentiation of Polycyclic Aromatic Hydrocarbons. $18,000

ACS-PRF Grants for Fundamental Research in the Petroleum Field (Type SE)

Harold H. Schobert, on behalf of Pennsylvania State U. Recent Advances in Coal Science, ACS National Meeting, Miami Beach, fall 1989. $3400

Michael T. Pope, on behalf of Georgetown U. Polyoxometal Cluster Complexes: Reactivity, Structures, and Biological Activity, International Chemical Congress of Pacific Basin Societies, Honolulu, December 1989. $2550

J. M. Drake, on behalf of the ACS Polymer Division. Molecular Dynamics in Small Finite Systems, ACS National Meeting, Miami Beach, fall 1989. $3400

Jon M. Bellama, on behalf of the U of Maryland. Group IV Elements: Biogeochemistry, Pharmacology, Technology, and Relationships of Neighboring Groups, International Chemical Congress of Pacific Basin Societies, Honolulu, December 1989. $3400

George Christou, John G. Reynolds, on behalf of Indiana U. Inorganic Modeling of Hydrodesulfurization, Hydrodenitrification, Hydrodemetallation Petroleum Chemistry, ACS National Meeting, Boston, spring 1990. $3400

John T. Welch, on behalf of the Research Foundation, State U of New York. The Effects of Selective Fluorination on Reactivity, ACS National Meeting, Boston, spring 1990. $3400

Lester R. Morss, Jean Fuger, on behalf of the ACS Division of Nuclear Chemistry & Technology. International Symposium To Commemorate the 50th Anniversary of the Discovery of Transuranium Elements, ACS National Meeting, Washington, D.C., fall 1990. $3400

Andrzej Wieckowski, on behalf of the Board of Trustees, U of Illinois. Nuclear Methods in Surface Electrochemistry, 177th Meeting of the Electrochemical Society, Montreal, May 1990. $3400

Kenneth J. Takeuchi, Daryle H. Busch, on behalf of the Research Foundation, State U of New York. Ligand Design in Regulating Redox Reactions, ACS National Meeting, Washington, D.C., fall 1990. $3400

David R. Tyler, Richard G. Finke, on behalf of the U of Oregon. Organometallic Reaction Mechanisms, ACS National Meeting, Miami Beach, fall 1989. $1700

Theodore Mill, on behalf of the ACS Division of Organic Chemistry. Free Radical Chemistry, ACS National Meeting, Miami Beach, fall 1989. $1665

James C. Martin, on behalf of Vanderbilt U. Recent Advances in Bonding at Main Group Element Centers: Structure and Theory, International Chemical Congress of Pacific Basin Societies, Honolulu, December 1989. $1700

Luigi G. Marzilli, on behalf of Emory U. Exploitation and Application of Biotechnology: Opportunities for Inorganic Chemistry, ACS National Meeting, Boston, spring 1990. $3400

Robert E. Botto, on behalf of the ACS Division of Fuel Chemistry. Magnetic Resonance of Solid Carbonaceous Fuels, International Chemical Congress of Pacific Basin Societies, Honolulu, December 1989. $3400

Thomas P. Fehlner, on behalf of the U of Notre Dame. Inorganometallic Chemistry—the Metal-Nonmetal Bond, ACS National Meeting, Washington, D.C., fall 1990. $3400

Patrick G. Hatcher, on behalf of the ACS Division of Geochemistry. Humic Substances: Geochemistry, Structure, Agricultural and Environmental Role, and Industrial Utilization, ACS National Meeting, Miami Beach, fall 1989. $3000

James R. Herring, on behalf of the ACS Division of Geochemistry. Crustal Geochemical Cycles, ACS National Meeting, fall 1989. $3400

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